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Series of Monograph Supplements

After-Images

SHEPHERD IVORY FRANZ

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THE

Psychological Review

EDITED BY

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After-Images

BY

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CONTENTS.

ON AFTER-IMAGES.

INTRODUCTION.

After-images were first described in the *De Somniis* by Aristotle, who regarded them as closely allied to the centrally excited images of the dream-state; they were rediscovered and described anew by St. Augustine, and again by the Arab Alhazan (a student of Aristotle's works) in the eleventh century. Peiresc, in describing these appearances in the seventeenth century, thought that he had discovered a new phenomenon. Among other prominent investigators to note and experiment with the images were Boyle, Newton, Buffon, Goethe, the elder Darwin and Fechner.

These vestiges of sensation owe their present interest in large measure to their seemingly twofold character, being allied both to sensation and to memory- and imagination-images. To the earlier observers after-images were more nearly like the images of the imagination; later, they were considered almost a sensation; whilst most recently the original position of Aristotle is again prominent. In the history of after-images we seem to have an epitome of the interrelations of physics, physiology and psychology; and probably no other single phenomenon is so good an example of the growth of experiment and measurement in psychology.

The succeeding portions of the present monograph, apart from the bibliography, deal respectively with (1) an experimental analysis of the conditions affecting the production, the duration, the latent period, the space-relations, etc., of the after-image, and with (2) a history of the phenomena and their relation to sensation, to imagination and to memory.

In the bibliography I have given references to what seem the most important contributions on the general subject of after-images. In Professor Koenig's excellent bibliography[1] of

[1] Helmholtz, Handbuch der Physiologischen Optik, 2te Aufl.

vision will be found references to almost all the work on this subject done previous to 1894. In the numbers of the *Psychological Index*, and in the bibliographies in the *Zeitschrift für Psychologie* and in the *L'Année Psychologique* will be found references to current literature since 1893.

The experiments to be subsequently described were all made in the psychological laboratory of Columbia University; and as subjects eleven advanced students in psychology took part, viz., B, C, D, F, G, H, Ho, K, M, S and W. Other subjects, too numerous to mention individually, chosen for their *naïveté*, were used for check-experiments. To all I am greatly indebted for their help and suggestions throughout the progress of the research.

The terminology used in the succeeding portions is as follows: (1) Positive after-image is an after-image in which the image and its background bear the same intensity-relation as in the stimulus. (2) Negative image is one in which the relation of intensity is reversed. Thus, if the stimulus is a red cross on a black background, and the resultant after-image is projected on a white wall, the image will be darker than the background, and accordingly negative; if the image is projected on gray, it may be darker or lighter than the field and either negative or positive. In either case the image may be of the same color as the original or of a different color. Four different kinds of images must then be distinguished, viz.:

$$\text{Positive}\begin{cases}\text{same-colored.}\\\text{other-colored.}\end{cases}\qquad\text{Negative}\begin{cases}\text{same-colored.}\\\text{other-colored.}\end{cases}$$

Wundt's definitions, (1) that the image is positive when it is of the same or greater intensity than the stimulus, and negative when it is of lesser intensity;[1] and (2) that positive images are same-colored and negative, are other-colored,[2] have not been accepted by the most recent and best writers.

[1] Grundzüge der Physiologische Psychologie, 4 Ed., I., 513.
[2] Human and Animal Psychology, Eng. trans., p. 109.

PART I. EXPERIMENTAL.

SECTION 1. APPARATUS AND METHODS.—The apparatus used throughout the series on threshold, latent period and duration was that used by Fullerton and Cattell,[1] adapted by the writer for the present purposes. The accompanying illustration shows the instrument from the standpoint of the experimenter.

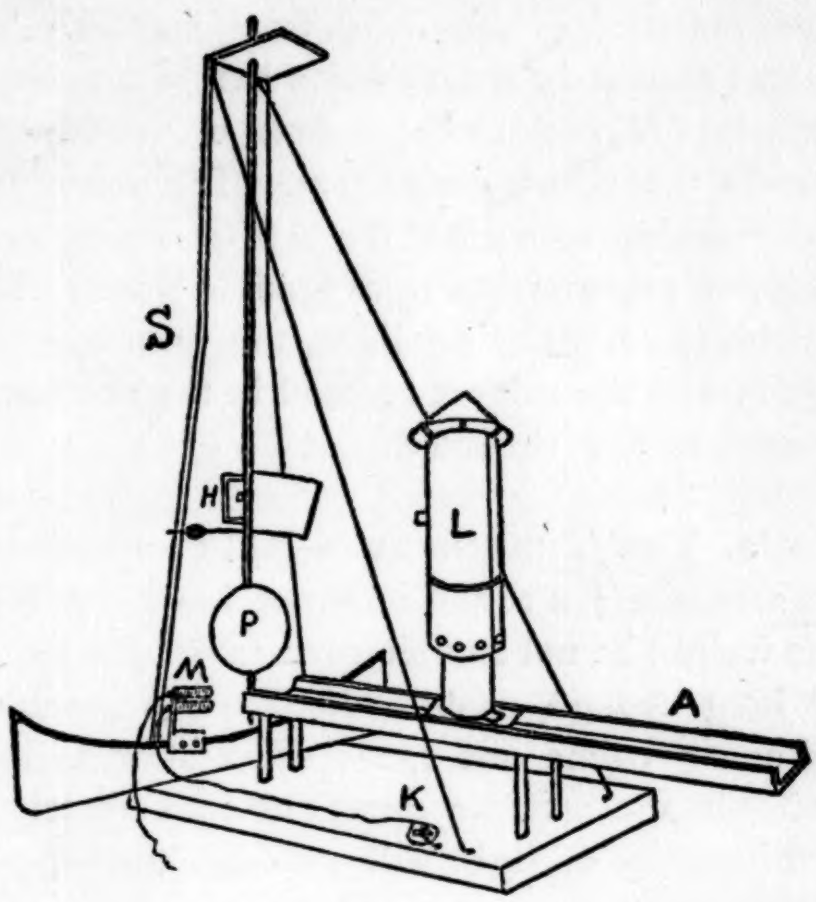


FIG. 1.

The apparatus consists of a vertical screen (*S*) with an adjustable opening (*H*), of a long arm (*A*) and of a screen pendulum (*P*). At the opening (*H*) arrangements were made for inserting ground-glass plates for equalizing the illumination of the stimulus and for rapidly changing the areas. The long arm (*A*) carried a kerosene-lamp (*L*) (in the experiments upon duration and latent period an electric arc lamp), the changes in intensity being made by moving the source of light toward and from the observer. On the pendulum (*P*) was a screen, which

[1] Perception of Small Differences, p. 135; University of Pennsylvania Press, 1892.

in its usual position, as the pendulum is held up by the electro-magnet (*M*), shuts off the light from the area to be illumined at (*H*). When the pendulum is released, however, the light shines on the area for one second, and, returning, it is caught up by the electro-magnet. The key (*K*) was used to make and break a circuit to the electro-magnet (*M*) for releasing and holding the pendulum. Before the upright screen (*S*) is a tachistoscope (not shown in the figure), with drop screens to give a light-stimulation of $\frac{1}{1000}$, $\frac{1}{100}$, or $\frac{1}{10}$ second. The whole instrument was placed in a dark-room before a cabinet with an opening opposite (*H*). All experiments, unless otherwise noted hereafter, were made in a dark-room. The subject remained inside the dark-cabinet for from ten to fifteen minutes for adaptation before any experiments were made. Then, with the eyes on a level with the stimulating light, the area was uncovered, covered again, and the subject reacted in the manner appropriate to the series of experiments.

SECTION 2. THE THRESHOLD.[1]—Not every stimulus is followed by a sensation; a sound may not have the requisite intensity; the weight be not sufficiently heavy; the light not large enough or long enough continued. In like manner minimal amounts of energy, time and space stimulation will fail to produce an after-image. Some questions immediately suggested are: What intensity of light will produce the after-sensation? How large an area is necessary to get an after-image? How long must the stimulus last to leave its effect? Then, we may ask whether or not there is a relation between the varying changes in the light, whereby a small area may be counterbalanced by a longer stimulation or by a greater intensity, and *vice versa*.

Time.—As noted above, three variables were used, viz., time, area and intensity. With a fixed area and intensity, what time must the light stimulate the eye to produce an after-image? The lamp placed at 25 cm. from the screen *S*, giving an intensity of $\frac{2}{25}$ c.p., and the area 64 sq. mm., were used

[1] Sec. 2 is largely reprinted from an article on The After-image Threshold; *Psychol. Rev.*, II., 130-136 (1896).

as constants throughout this series. The time was varied from $\frac{1}{1000}$ to 1 second. Two intermediate steps were used, $\frac{1}{100}$ and $\frac{1}{10}$ second.

Adaptation completed, the subject sat in position, a stimulus was given, and the subject announced the appearance or non-appearance of an after-image. Usually thirty to forty minutes were taken for each day's experiments, the series being stopped before fatigue became apparent. For each subject the number of experiments upon each variation in time was one hundred. Where a greater or less number were made the small numbers in parentheses in the appropriate columns of the tables show how many tests of this kind were made. The experiments were all made with the eyes open, so as not to disturb the after-image. The subject's eyes were at the normal distance (about 30 cm.) from the stimulus; his head was steadied by a support. Rests were taken between the separate experiments to allow any trace of the previous image to disappear, a signal was given, five seconds were allowed for preparation and the light was shown.

The intensity of the light was very constant. The lamp was trimmed before the whole series of experiments; and the photometric determinations made before, during and after a sitting showed only the variations likely to occur in any series with the photometer used (Bunsen's). A fixation-point could not be secured throughout the experiments. At first this was a somewhat disturbing factor; but as the light used as a stimulus was so small and the after-image so indistinct, it was judged best not to have a fixation-point of light, owing to the confusion likely to result from mistaking it for an after-image. With practice, however, the observer learned to look for the stimulus in the proper direction; and in the case of the writer in not over 5 per cent. of the times was it necessary to focus the eyes consciously after any part of the light was seen.

The following table shows the results of the experiments for time obtained from two observers, C, an advanced student of psychology, and F, the writer, upon whom the experiments were made by another worker familiar with the apparatus. The table shows on the first lines the percentages of times that after-images appeared. The results were also grouped in

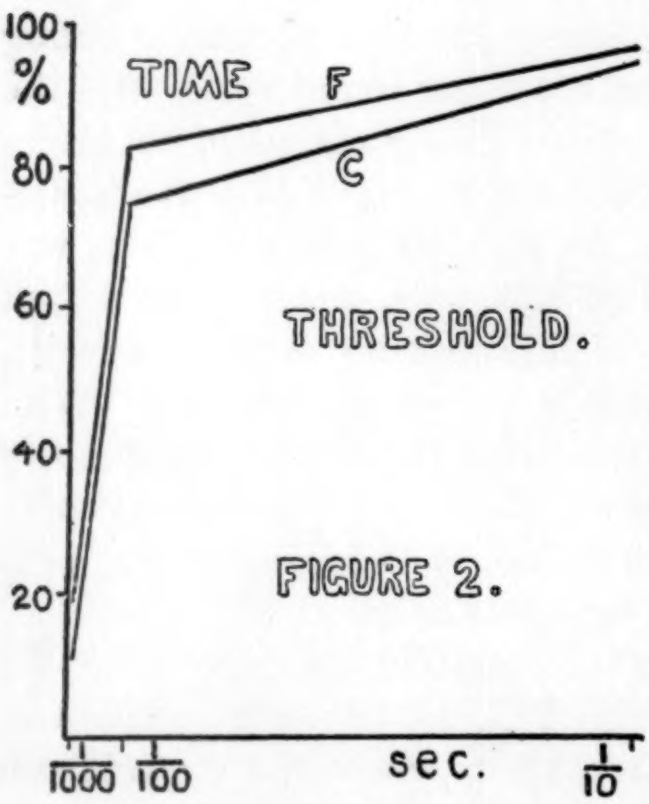
series of tens, and the variations of these groups were calculated. These variations are shown on the second lines, marked A. var.

TABLE I.—TIME.

Time in sec. Subjects.		1	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{1000}$
C.	Per cent.	97	95	75	12
	A. var.	3.5(70)	7.	17	10.8
F.	Per cent.	100	97	82.5	19
	A. var.	—	4.2	8.3(120)	7.4
Average.		99	96	79	15.5

As noted above, 100 experiments of each kind were made, except where another figure is shown in parentheses. Thus, for F, with the stimulus $\frac{1}{100}$ second, 120 experiments were made; while for C, using one second stimulation, only 70 trials were made.

The accompanying curve shows the results graphically—the abscissa denoting divisions of time, the ordinate the percentage of times after-images appeared. Only the points for $\frac{1}{1000}$, $\frac{1}{100}$, and $\frac{1}{10}$ seconds are shown.



The shape of the curve indicates what might have been expected in accordance with the results of experiments upon other time-phenomena of vision. With the shortest time after-images seldom appeared; then with a slight increase in the duration of the stimulus there was a rapid rise in the number of appearances, followed by only a slight increase for longer stimulation. The same character of curve is found in investigating the time it takes to see a light or a color.

When shown for a very short time the color can never be seen; but as the time is slowly increased, it becomes very plain, but is seen no oftener and becomes no plainer if the time be further increased. In both cases (recognizing a color and seeing after-images) the stimulus at first is insufficient to make the sensation appear above the threshold of conscious experience. This threshold is then passed suddenly, and the stimulus soon reaches a point at which an after-image or the color (as the case may be) is always seen, unless numerous distractions of great intensity interfere.

This effect of increase in the time of stimulation is quite in accord with the commonly accepted theory regarding the after-image: that the phenomenon, at least in its positive form, is due to inertia of the retina. From this point of view, the longer the light works upon the retina—the greater the amount of energy used—the greater will be the effect on consciousness.

Area.—A corresponding, though not a proportionate, increase in the number of appearances was noted when the area was varied from $\frac{1}{16}$ to 64 sq. mm. Six areas were used—squares of ¼, ½, 1, 2, 4 and 8 mm. on each side. These were made on ground glass, opaque paper being glued over all but the small area wanted. The error in making the larger sizes was less than ¼ mm., which amount is inappreciable in comparison with the whole area. Difficulty was experienced in making the areas under 1 mm.; but from numerous ones made the best were chosen. In those chosen the error was not more than $\frac{1}{10}$ mm. The smallest areas were measured with a magnifying-glass, and those were chosen in which the errors compensated each other.

The intensity of the light was kept at $\frac{2}{25}$ c. p., and the time of stimulation was one second. With these constant, an after-image was very seldom seen when the smallest area was used, while the largest square produced an image at all times. The same precautions that were observed in the experiments upon the effect of time-changes were taken in this series and in all the experiments that are described later.

The following table and accompanying curve give the results obtained. The figures in the table are as in Table I.:

first are given the changes in stimulation, then the percentage of times the image was seen under these conditions and then the average variations of the experiments when grouped in sets of ten. The abscissa of the curve denotes the relative amount of the stimulus; the ordinate shows the percentage of times after-images were seen.

TABLE II.—AREA.

Area in sq. mm. Subjects.	64	16	4	1	$\frac{1}{4}$	$\frac{1}{16}$
M. Per cent.	100	90	72	52	27	20
M. A. var.	—(50)	7.5(80)	14.8	12.4	9.2	6
F. Per cent.	100	96	88	57	31	8
F. A. var.	—	4.8	8.8	13	15.4	8
Average.	100	93	80	54.5	29	14

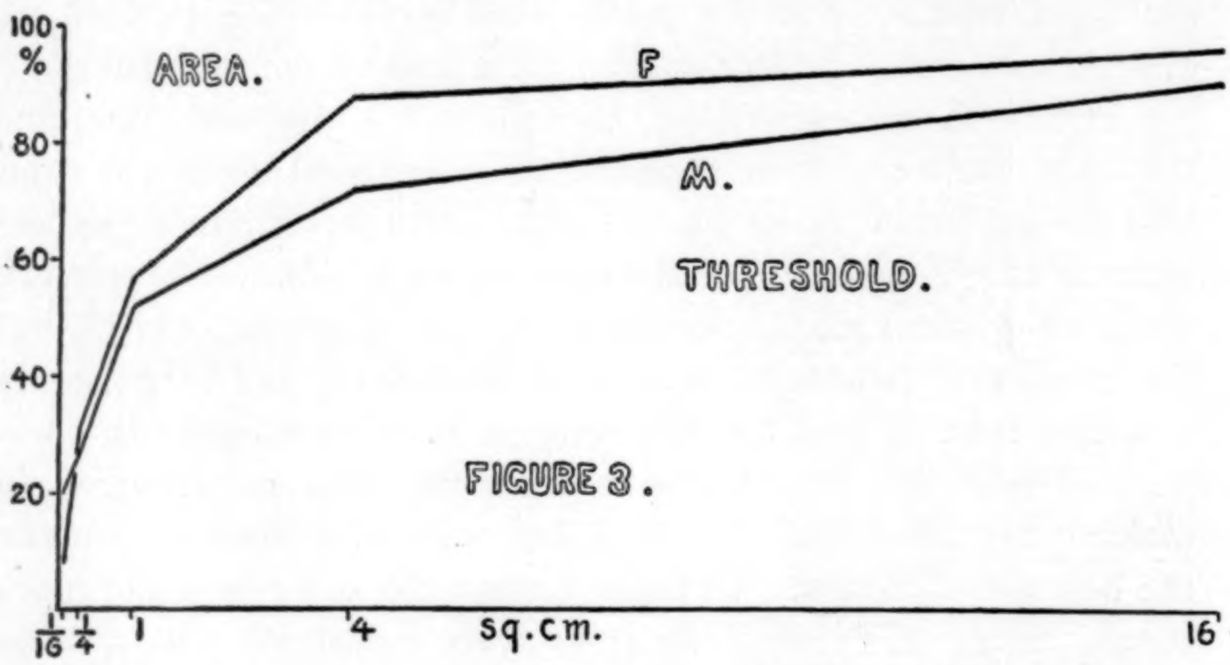


FIGURE 3.

Some preliminary work in which a different standard of intensity was used—$\frac{1}{20}$ candle power—shows the same effect of area-increase. These experiments were made before the general line of work was fully planned. Seventy experiments were made with each area, and the writer was the only subject. The results, because of their confirmatory character, are appended:

TABLE III.—AREA.

Area in sq. mm.	64	16	4	1	$\frac{1}{4}$
F. Per cent.	96	89	67	41	19
F. A. var.	5	10	14.7	10	9.9

A priori, one might not expect such an increase in the number of appearances to follow an increase in the size of the stimulus. For, with intensity and a time of stimulation constant, one might well say that the structure of the eye is such that only the number of stimulated elements, not the stimulation of the individual elements, changes with any increase in size of the physical stimulus. This is undoubtedly true, and the result is paralleled by the results of experiments upon the extensive threshold of vision. A color or a light cannot be seen when only a small area is present; but on increasing the size it is readily perceived. This may be analogous to the so-called 'summation process,' or it may and probably can be resolved into a matter of the attention. As a matter of fact, the largest area may not produce any more after-images than the smallest. The apparent difference may be the result of inability of the smallest sensations to fix the attention.

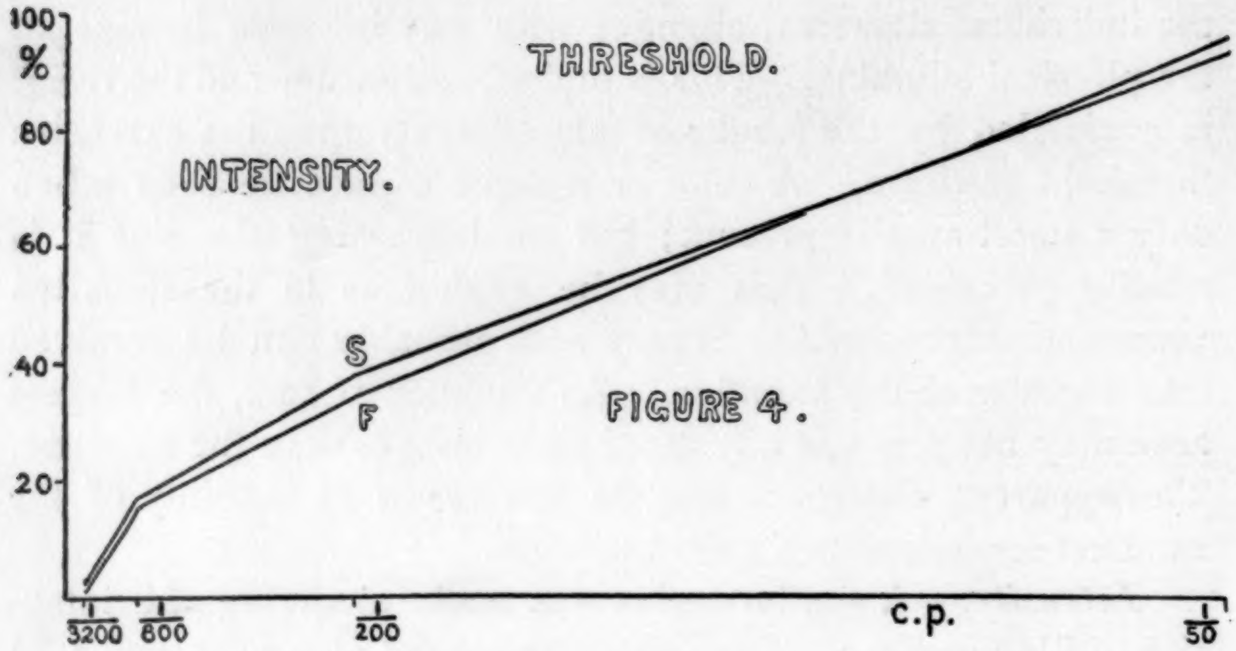
Intensity.—A similar series was made changing the intensity of illumination. The lamp was moved along the arm (*A*) of the apparatus (see Fig. 1) so as to give intensities varying from $\frac{2}{25}$ to $\frac{1}{3200}$ c.p. Three intermediate steps were chosen for convenience—$\frac{1}{50}$, $\frac{1}{200}$ and $\frac{1}{800}$ c.p. The amounts of energy in these experiments had an effect corresponding to what was found for the changes in the time and in the area of stimulation. The results obtained and a graphic representation follow:

TABLE IV.—INTENSITY.

Intens. in c.p. Subjects.		$\frac{2}{25}$	$\frac{1}{50}$	$\frac{1}{200}$	$\frac{1}{800}$	$\frac{1}{3200}$
S.	Per cent.	100	94	48	17	2
	A. var.	— (80)	7	25 (110)	20.8 (110)	3.6
F.	Per cent.	100	96	44	15.5	1
	A. var.	—	5.4	19.5(130)	13.5 (130)	1.8
Average.		100	95	46	46	1.5

Two results in Tables I., II., III. and IV. should be noted: (1) the close correspondence of the observers, and (2) the comparatively large variation for the different individuals. The first of these observations is, I believe, of little significance.

The great variation, however, seems to point to a considerable mental influence affecting the appearances. This will probably be more clearly brought out in the discussion of the experiments upon the influences determining the duration of the after-image.



Summary.—Experiments were made upon four trained subjects to find the amount of time-, area- and intensity-stimulation that would produce an after-image (conscious). It was found that to see an after-image 75 per cent. of the times the eye is stimulated, it is necessary to have as stimulation (1) for $\frac{1}{100}$ second and 64 sq. mm. surface of light, an intensity of $\frac{2}{25}$ c. p.; or (2) for one second exposure, an area of 4 sq. mm. and an intensity of $\frac{2}{25}$ c.p.; or (3) for 1 second exposure, an area of 64 sq. mm. and a light of $\frac{1}{100}$ c. p.

The average results for the three series are indicated in the following curve, which gives a general view of the relative effects of the physical units. It will be seen that the effects of time, intensity and extensity-changes are varied. This shows that for physiological or mental processes the units of physical energy do not counterbalance. The compensating relation seems to be a rather complex one. In its simplest form this relation may be stated as follows: squaring the time equals doubling the intensity or quadrupling the area; and *vice versa*, reducing the area to one quarter equals halving the intensity or taking the square root of the time.

Based upon the well-known phenomena of color-mixing by means of Maxwell's discs, the objection may be raised to these conclusions that lights of much less intensity produce after-images, inasmuch as colors fuse in any illumination. While this is true, it should not be forgotten, on the other hand, that the after-images producing the fusion are not consciously perceived as after-images. The usually low intensity of light in conjunction with a short time of stimulation does not produce an after-image that can be consciously noted. Moreover, the overlappings of images and succeeding stimuli produce a total effect which lacks many of the distinctive features of the simple after-image.

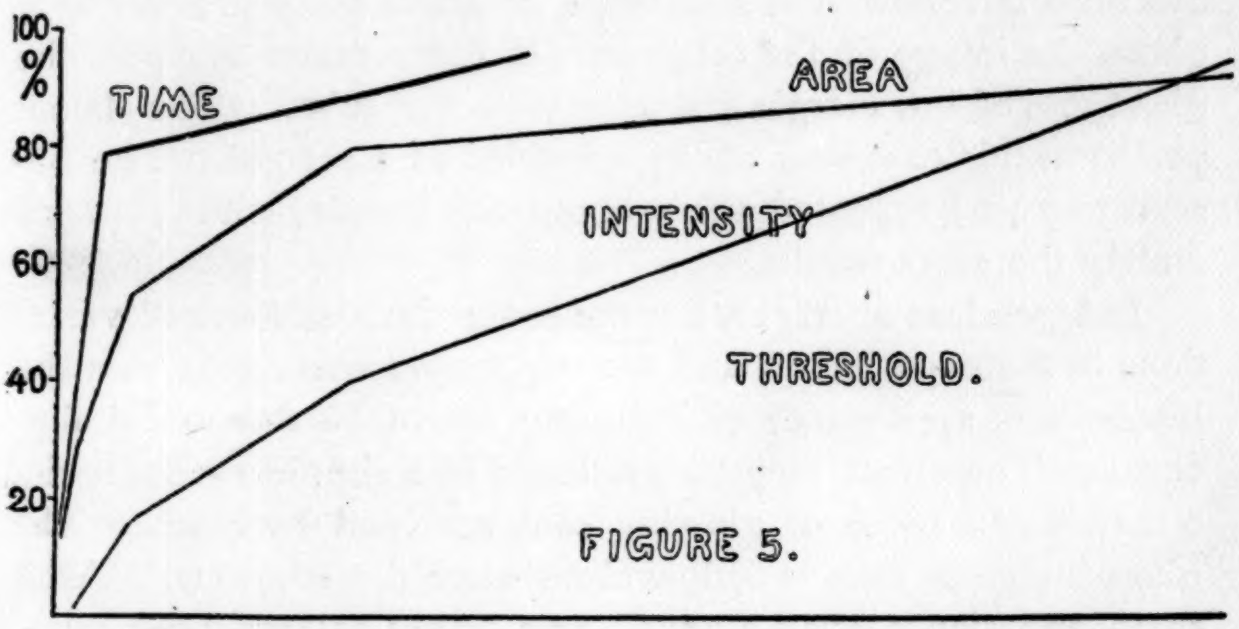


FIGURE 5.

During the three series of over 3000 experiments only five times were negative after-images seen. These were noticed only with the largest area, the longest time and the greatest intensity, and always toward the close of an hour's session after the eyes had been stimulated forty or fifty times. This fact would seem to support the hypothesis that the negative after-image is due to eye-exhaustion.

SECTION 3. THE LATENT PERIOD.—That a light does not immediately produce an after-image is now well known. The observation seems to have been made first by Young,[1] in 1872,

[1] C. A. Young, Note on Recurrent Vision; *Taylor's Philos. Mag.*, 4 Ser. XLIII., 343–345, 1872.

who, in using a Holtz machine which gave a large spark, noted that if a single spark was made any conspicuous object in the darkened room was seen at least twice—with an interval of a trifle less than a quarter of a second—the first time vividly, the second time faintly; often the object was seen a third and sometimes (but only with great difficulty) even a fourth time. This interval between the sensation and the after-image has been called the latent period.

Young's observation seems to have been quite forgotten for several years till the appearance of Bidwell's note on the image following an illumined vacuum tube.[1] Bidwell found that, if a Geissler tube be revolved at the rate of once in three seconds, the tube is followed at a distance of about forty degrees by a ghost-like image of the original. If the rotation stopped, the ghost moved on, merging finally with the tube. The latent period in this case was about one-third of a second. The observation was repeated upon about ten people, with approximately the same results.

Independent observers[2] at the same time announced variations in the experiment, and the suggestion was made that the intermittent appearance of lightning might be due to a similar cause. The effect may be produced in a simple manner with a match or a piece of glowing coal revolved by hand. The ghost-image is seen to follow close after the stimulus. After some experience even a pencil or a bright-colored book when moved shows the phenomenon.

Later and more exact measurements of the appearances have been made by Bidwell,[3] Charpentier[4] and Hess.[5] Charpentier repeated Bidwell's observations and noted a second appearance after the sensation, as Young and Bidwell had. This, he adds, is easier to note in indirect than in direct vision. A similar os-

[1] S. Bidwell, On Certain Spectral Images Produced by a Rotating Vacuum Tube; *Nature*, XXXII., 30–31, 1885.

[2] Davis, Laurin, Newall and others.

[3] On the Recurrent Images following Visual Impressions; *Proc. Roy. Soc.*, LVI., 132–145, 1894.

[4] Réaction oscillatoire de la rétine sous l'influence des excitations lumineuses; *Arch. de Physiol.* (Ser. 5), IV., 541–553, 1892.

[5] Untersuchungen über die nach kurzdauernder Reizung des Sehorgans; *Archiv f. die gesammte Physiol.*, XLIX., 190–208, 1891.

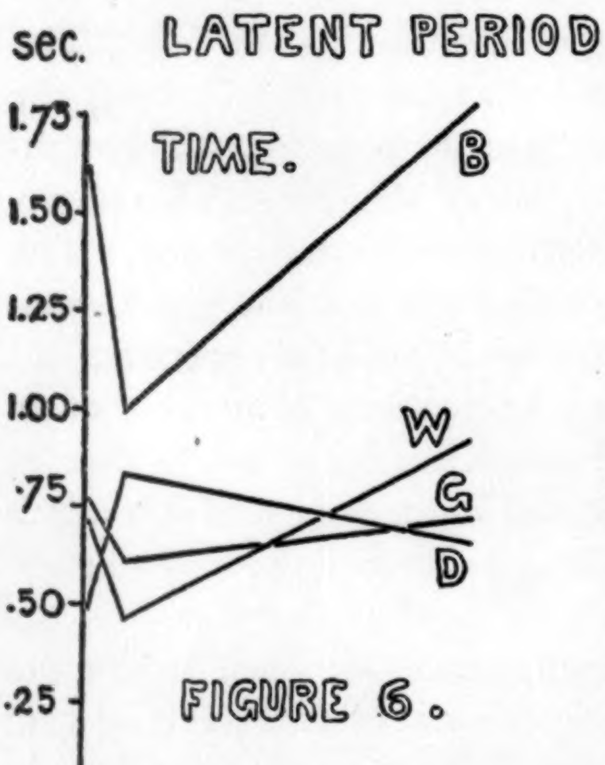
cillatory effect was found by Charpentier in using a black disc with a comparatively small white sector. Revolving the disc once every second or every two seconds, and fixating the center, the white sector was seen to be crossed in places by dark bands. These seem closely related to the disappearances and the reappearances of the after-image, but need more careful study in the light of Exner's work upon the progress of a visual sensation.

Bidwell's later work is largely a repetition of his earlier observations, but using spectrum colors instead of the illuminated Geissler tube. A spectrum, revolving every 1 1/2 seconds, was thrown on a screen and the ghost-image observed. The ghost followed the spectrum at a distance of about 50 degrees. The latent time was 0.2 second. It is interesting to note that Bidwell observed no image following red or violet light. The recurrent image of an illumined slit in an opaque disc was found to follow after 0.15 second. Another disc, 15 cm. diameter, having two opposite radial slits 1/2 mm. wide, was then rotated one turn a second before illumined ground glass. As observed from a distance of 1 1/2 meters, each slit seemed to give four and possibly five luminous images arranged like the ribs of a fan. The usual blue recurrent image could also be seen following the images of the radial slits at an angle of 80 degrees. Throughout, the eye was fixed upon the center of the disc. This observation is readily confirmed, but seems not to be understood. The fact that Bidwell speaks of the oscillations and the ghost separately seems to indicate that he did not believe they were similar in character. Even if we admit Charpentier's contention of an oscillatory process in the retina, which makes a white disc at any phase seem alternately dark and light, we could not admit it for the dark opaque disc of Bidwell nor for the after-image accompanying it.

One fact seems to have escaped notice—at least it has not been recorded. In the simple experiment with a burning coal or with a Geissler tube the ghost follows the stimulus; but, in addition, there is an after-image of the path taken by the light. In this image the oscillations described by Bidwell do not occur. None of the fluctuations usually apparent in the after-image are noted in this case, the image gradually fading away.

Experiments of a different character have been made by Hess. In his work moving objects were not used, momentary illumination of a stationary stimulus taking the place of the revolving discs. A photographic shutter gave exposures of $\frac{1}{100}$ to $\frac{1}{200}$ second. Hess discovered a negative after-image of very short duration following immediately upon the termination of the stimulus. This preceded what is commonly known as the positive after-image.

The nature of the experiments in the present work is more nearly related to the work of Hess than to that of Charpentier and Bidwell. A stationary light was used and the reaction-time taken. As in the work on threshold, I endeavored to find the relative effects of varying stimuli in the three respects of intensity, time and area. The apparatus used was essentially the same as that described in Section 1. The kerosene lamp, however, was replaced by an arc light of about 1000 c. p. The intensities, as given to the subjects, were 1, $\frac{1}{10}$ and $\frac{1}{100}$ c. p.; these were obtained as in the threshold-experiments. $\frac{1}{4}$, 1 and 4 sq. cm. in squares were used as areas, and the varying times were $\frac{1}{100}$, $\frac{1}{10}$ and 1 second. As constants were used $\frac{1}{10}$ c. p., 1 sq. cm. and 1 sec. Only one of the factors was varied at any one time. A chronoscope was placed in series with a reaction key and the pendulum (P) and the drop tachistoscope. The observer was instructed to react the instant the after-image appeared, and the time between the end of the stimulus and the beginning of the after-image could thus be read direct from the chronoscope.



The individual variation is quite large, owing to the mental attitude of the subject, one reacting to the first approximation

of an after-image, another waiting till he was certain that the appearance was what he sought. Although his attitude was constant with each individual, we shall not be able to compare the subjects, and to group them for an average representing a typical result. So also the individual attitude toward the stimuli made other variations in the results. To one the stimuli of greatest intensity were too bright; at times another could scarcely get an after-image with the smallest area.

Accompanying will be found the tables and curves for the average results for time-, area- and intensity-experiments upon four subjects. Twenty experiments were made upon each variable. In the tables the average time between the stimulus and the first appearance of the after-image is first given, and this is followed by the average variations of the twenty experiments.

TABLE V.

TIME: constants, $\frac{1}{10}$ candle power, 1 sq. cm.

Stimulus in Seconds. Subjects.	.01 Aver.	.01 A. Var.	.1 Aver.	.1 A. Var.	1.0 Aver.	1.0 A. Var.
B.	1.62	.42	.99	.12	1.76	.74
D.	.49	.19	.83	.35	.65	.11
G.	.76	.22	.61	.23	.71	.18
W.	.71	.13	.46	.14	.92	.20
Aver.	90		72		1.01	

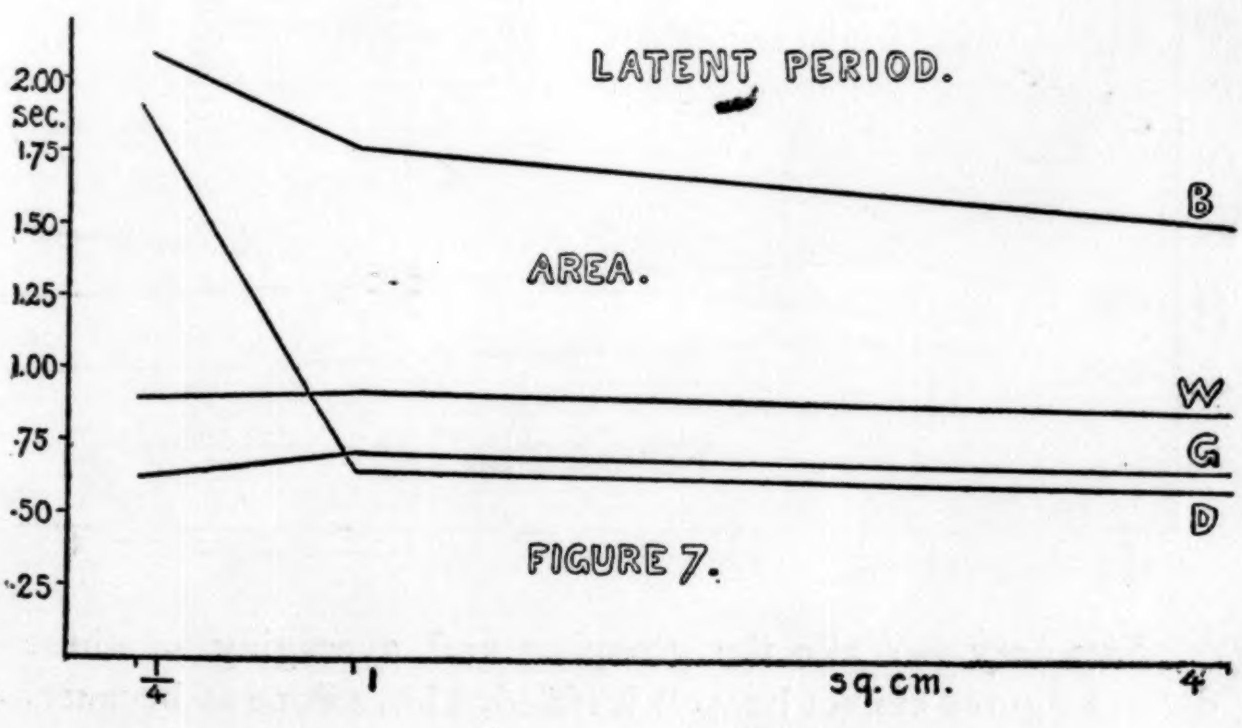


FIGURE 7.

TABLE VI.

AREA: constants, 1 sec., and $\frac{1}{10}$ c. p.

Area in sq. cm. Subjects.	¼ Aver.	A. Var.	1 Aver.	A. Var.	4 Aver.	A. Var.
B.	2.11	.65	1.76	.74	1.50	.46
D.	1.91	1.25	.65	.11	.58	.07
G.	.63	.13	.71	.18	.65	.11
W.	.90	.15	.92	.20	.86	.13
Aver.	1.39		1.01		.90	

TABLE VII.

INTENSITY: constants, 1 sec., and 1 sq. cm.

Intensity in c. p. Subjects.	.01 Aver.	A. Var.	.1 Aver.	A. Var.	1.0 Aver.	A. Var.
B.	1.39	.34	1.76	.74	3.36	1.58
D.	.57	.08	.65	.11	.51	.14
G.	.67	.12	.71	.18	1.09	.33
W.	.77	.13	.92	.20	.72	.11
Aver.	.85		1.01		1.42	

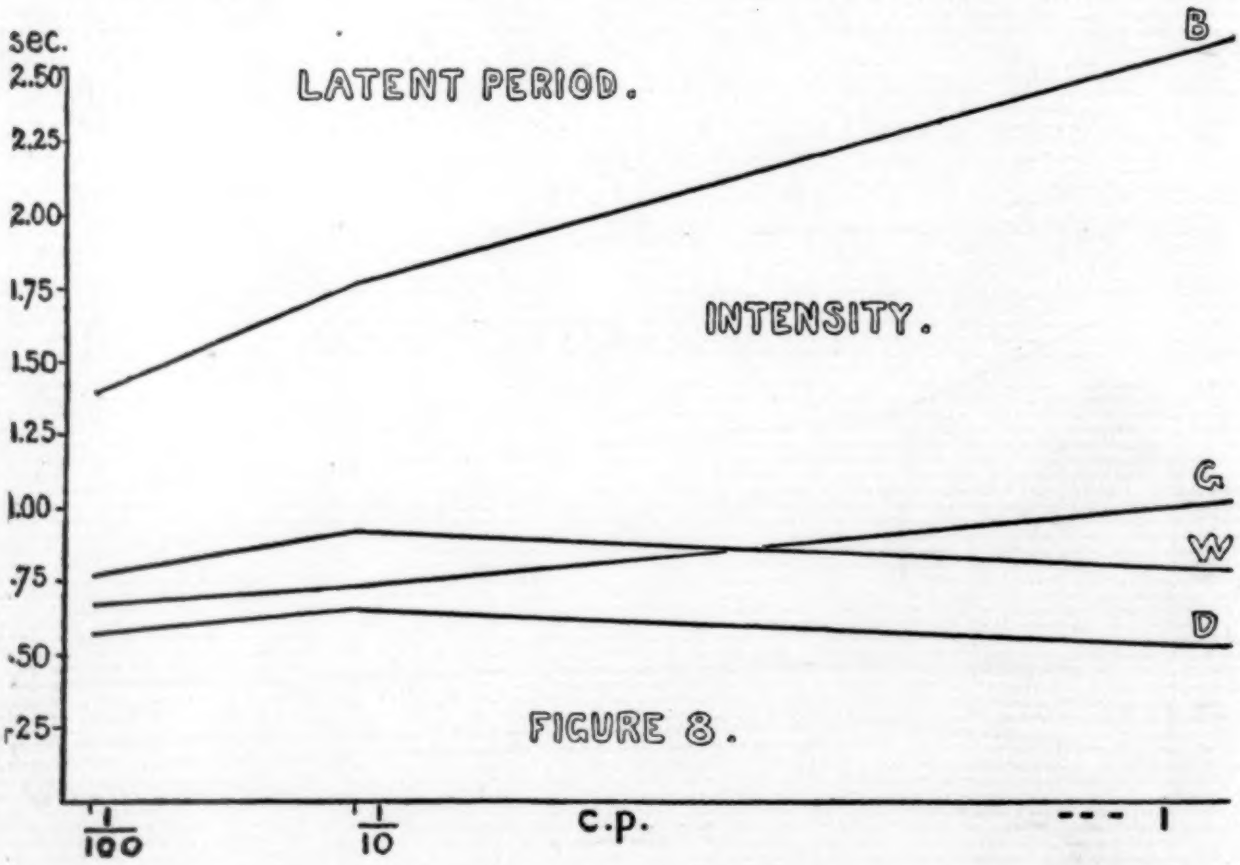


FIGURE 8.

Summary.—While the grouping and averaging of these diverse figures cannot be well justified, I have done so because,

in a general way, the figures of the averages seem to show what ordinarily would be expected. With the lesser times the eyes have not time to move and to get a sensation on many contiguous portions of the retina. Accordingly when the time of stimulation is short the after-images are clearer and more easily recognized. The larger areas have the advantage of giving after-images of considerable size, which attract the attention sooner than the smaller ones; while the great intensities seem to be so blinding in their effect that the image is very hard to recognize. I append a curve showing the comparative effects of the variables, but with full knowledge that its meaning should not be taken as absolute, but only as an indication of the results that a much larger number of individuals may approximate.

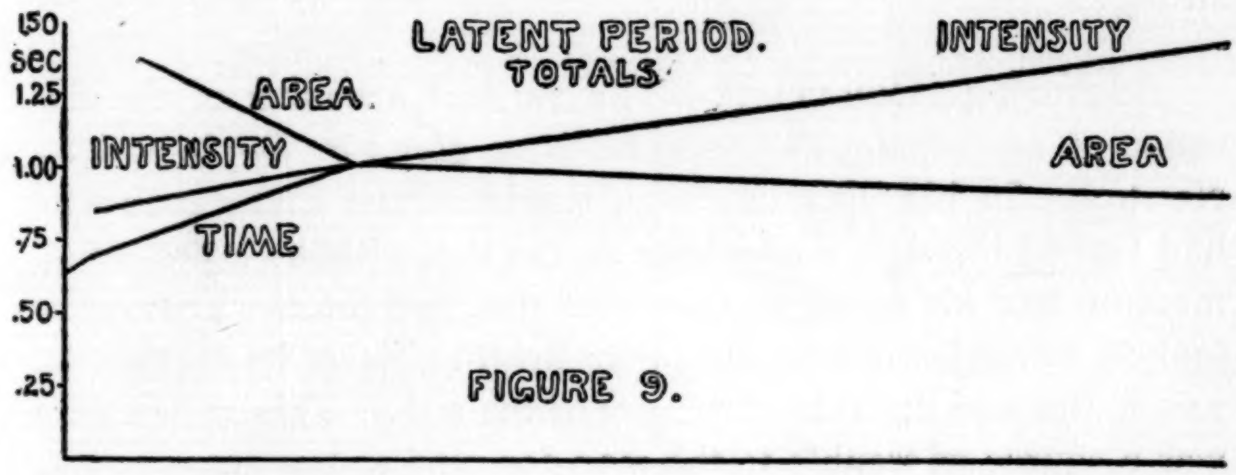


FIGURE 9.

In the existing theories explaining the phenomena no reason is noted for any variation in this latent period. It seems probable that an explanation must be looked for in the mental attitude of the subject. Such an explanation would not only account for the great individual differences, but would also account for the great variation of the same individual under precisely the same physical conditions. The subject G, who is distinctly visual, accustomed to note variations in color, etc., apparently recognized the image sooner than any of the others who were not so trained. This mental attitude will also explain why the after-image of the largest areas was seen sooner than that of the smaller one. The attention in this case was probably attracted sooner to the large object. The conditions attending the changes in latent time for intensity- and time-ex-

periments are not so evident. In the intensity-experiments the subjects B and G, for whom the 1 c. p. stimulus was too strong, dominated thereby the totals. Considered in connection with the results of the experiments upon duration (Section 4), it seems likely that the attention is a predominant factor in all measurements of the phenomena.

This view is further strengthened if the average variations under the different conditions are considered. Usually those conditions which the subject considered favorable show the least variation. Thus, B felt that the $\frac{1}{100}$-second exposure was too short a time for him to see the after-image, and the great variation shows that there must have been some great disturbing factors. The same occurred with both G and B under stimulation of 1. c. p., which was considered by both as too strong.

Section 4. Duration.—The earliest accounts of the duration of after-images seem to be those given by Boyle and by Newton. In his work on color, Boyle relates that a man who had looked through a telescope at the sun without a protecting medium had his eyesight so injured that thereafter whenever he looked toward windows or other bright objects he fancied he saw a globe of light about the size of the sun. This appearance was a source of trouble to the man for nine or ten years.

To Locke, who had called his attention to this interesting observation, Newton wrote an account of a similar personal experience. The letter, which contains further observations of interest, is quoted fully:[1]

"The observations you mention in Mr. Boyle's book of colours, I once made upon myself with the hazard of my eyes. The manner was this: I looked a very little while upon the sun in a looking-glass with my right eye, and then turned my eyes into a dark corner of my chamber to observe the impression made, and the circles of colours which encompassed it, and how they decayed by degrees, and at last vanished. This I repeated a second and a third time. At the third time, when the phantasm of light and colours about it were almost vanished, intending my fancy upon them to see their last appearances, I found, to my amazement, that they began to return, and by little and little to become as lively and vivid as when I had newly looked upon the sun. But when I

[1] D. Brewster, Memoirs of the Life of Sir I. Newton; Edinburgh, 1855, Vol. I., p. 236:

ceased to intent my fancy upon them they began to vanish again. After this I found that as often as I went into the dark and intended my fancy upon them, as when a man looks earnestly to see anything which is difficult to be seen, I could make the phantasm return without looking any more upon the sun; and the oftener I made it return the more easily I could make it return again. And at length, by repeating this without looking any more at the sun, I made such an impression upon my eyes that, if I looked upon the clouds, or a book, or any light object, I saw upon it a round bright spot of light like the sun, and, which is still stranger, though *I looked upon the sun with my right eye only, and not with my left, yet my fancy began to make an impression upon my left eye as well as upon my right.* For if I shut my right eye, or looked upon a book or the clouds *with my left eye, I could see the spectrum of the sun almost as plain as with my right eye,* if I did but intend my fancy a little while upon it; for at first if I shut my right eye and looked with my left, the spectrum of the sun did not appear till I intended my fancy upon it; but by repeating this appeared every time more easy. And now in a few hours' time I had brought my eyes to such a pass that I could look upon no bright object with either eye, but I saw the sun before me, so that I durst neither write nor read; but to recover the use of my eyes shut myself up in my chamber made dark for three days together, and used all means to divert my imagination from the sun. For if I thought upon him I presently saw his picture, though I was in the dark. But by keeping in the dark, and employing my mind about other things, I began in three or four days to have some use of my eyes again; and by forbearing to look upon bright objects recovered them pretty well, though not so well, but that, for some months after, the spectrum of the sun began to return as often as I began to meditate upon the phenomena, even though I lay in bed at midnight with my curtains drawn."

Several interesting observations are here noted. The one of most importance seems to be that regarding the effect of imagination and attention upon the after-image. This will be discussed later; as will also the one regarding the transfer of the image from the right to the left eye.

The philosopher Tetens, who seems in some way to have anticipated the modern idea of mental measurement, mentions that he had investigated the duration of the after-image. Only a few words of description are given, and details were left for a future paper, no record of which I have been able to find.

Some few records of the duration are to be found in Fechner's observation of the color-changes, but the material is so slight as to be of little value.

Helmholtz notes that the duration and intensity of the stimulating light affect the duration and character of the resultant after-image: "The greater the intensity of the primary light the brighter is the positive after-image and the longer it con-

tinues."[1] "Greater intensity of the primary light gives the negative after-image greater clearness and duration."[2]

The most extended observation of the changes occurring in connection with the duration of the phenomena seem to be those by Titchener.[3] Used primarily for another purpose (see Section 8), the observations are of considerable value in this connection, because they were made upon subjects naïve as to the present problem. Dr. Titchener asked his subjects to record the duration of various after-images in a stimulated eye. These experiments, though few in number for the single observers, show in general the same effect as the more extended series by myself. The conditions were as follows: The subject was placed before a screen with a variable sized opening, which was to be illumined by a lamp. The photometric determination of the light is not given. The area- and time-stimulations were changed and the records taken. The light used was made vari-colored by the use of gelatin plates; white light was not used. The following table of results with red lights will illustrate the general tendency, and will act as a basis for comparison with the present work. In this table, which I have constructed from the individual records as given by Titchener, will be found the averages of at least three observers for each series. The maximum number of experiments made under any con-

Table VIII.

	Area of Stimulation in mm.		
Stimulation in seconds.	30	40	50
5		9.9 (14)	27.2 (9)
10	12.5 (14)	17.4 (16)	26.7 (8)
15	16.3 (15)	22. (14)	29.7 (7)
20	19.1 (10)	23.9 (15)	39. (8)
25	21.9 (11)	30.1 (10)	30.8 (7)

[1] Handbuch der Physiol. Optik, p. 503.

[2] Ibid., p. 505.

[3] E. B. Titchener, Ueber binoculare Wirkungen monocularer Reize; *Philos. Stud.*, VIII., 231–310 (1892).

dition by a subject was six, the minimum two. In parentheses will be found the number of experiments used in making the averages. The other figures give, in seconds, the average total duration of the after-image.

The individual variations from these averages are comparatively large, although each individual's results are quite constant. The variability is about the same as was found in my experiments upon the effect of time-, area- and intensity-changes.

The present series took its rise, however, largely from two incomplete minor studies made at the Columbia Psychological Laboratory, 1891–93. These investigations were begun by Mr. L. V. Southack and Miss E. G. Seebring, respectively; but the results and methods were unknown to the writer till after the present series was begun. The results, which have remained unpublished, I give in the appropriate place, with the corresponding present series. The method employed by both experimenters was to use an incandescent lamp, enclosed in a long box, to illumine a ground-glass Greek cross in the front of the box. Each arm of the cross was one square centimeter. Variations in intensity were obtained by changing the position of the lamp, and variations in time of stimulation were measured by means of a metronome. The results were written down by the observers after each experiment, the various fluctuations being noted as well as possible.

The apparatus for the present series was about the same as that used in the work on latent period; but for the chronoscope a kymograph was substituted. Upon this a continuous record of the after-image could be recorded. The time of stimulation was noted upon the drum, and the subject was instructed to close the key-circuit as soon as an after-image appeared, to keep it closed while the image lasted, and to break and make the circuit as quickly as possible when any changes in the character of the after-image took place. When any change was noted by the breaking or the closing of the circuit the subject told the experimenter its character, and this was indicated upon the kymograph-record. In this way not only the total, but the actual time of duration, the fluctuations and, to some extent, the latent

period could be determined. In this series the observations of the latent period were open to criticism owing to a slight degree of inaccuracy in recording the end of the stimulating light. Such an error was relatively large for the short times of the latent period, but was inappreciable for the comparatively long durations. As in the preceding work on threshold and latent period, the three physical units of energy were varied. A standard stimulus of 1 cm., $\frac{1}{10}$ c.p. and 5 seconds was chosen; and the variables were $\frac{1}{4}$, 1 and 4 sq. cm., $\frac{1}{100}$, $\frac{1}{10}$ and 1 c.p., and 1, 5 and 10 seconds. It was found impossible to record the exact time of each fluctuation. The changes in the character of the image are not clear-cut, but there is a fading of one color into another. This could not be recorded as a distinctive color-change. Even the usually marked changes from the positive to the negative phases were not always clear-cut.

The following tables and curves give two results: the total time of the after-image—*i. e.*, the time from the end of the stimulus to the final disappearance of the after-image; and the actual time—*i. e.*, the total time minus the period when unseen. In the curves the total durations are denoted by the continuous lines, and the actual times by the broken lines.

Time.—The constants in these experiments were an intensity of $\frac{1}{10}$ c.p. and an area of 1 sq. cm.

Table IX.

Total Duration of After-image.

Time of Stimulation in seconds.	1			5			10		
Subjects.	Aver.	A. Var.	No. Exp	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.
K.	32	6	20	56	24	20	56	14	20
H.	48	10	10	59	15	10	84	27	10
F.	29	4	10	32	5	10	34	4	10
M.	50	13	10	77	29	10	96	30	10
Average.	39.8		50	56		50	67.5		50

TABLE X.

ACTUAL DURATION OF AFTER-IMAGE.

Time of Stimulation in seconds.	1			5			10		
Subjects.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.
K.	26	4	20	40	12	20	40	9	20
H.	32	9	10	38	17	10	64	23	10
F.	25	2	10	30	5	10	29	3	10
M.	32	10	10	54	20	10	77	20	10
Average.	28.7		50	40.5		50	52.5		50

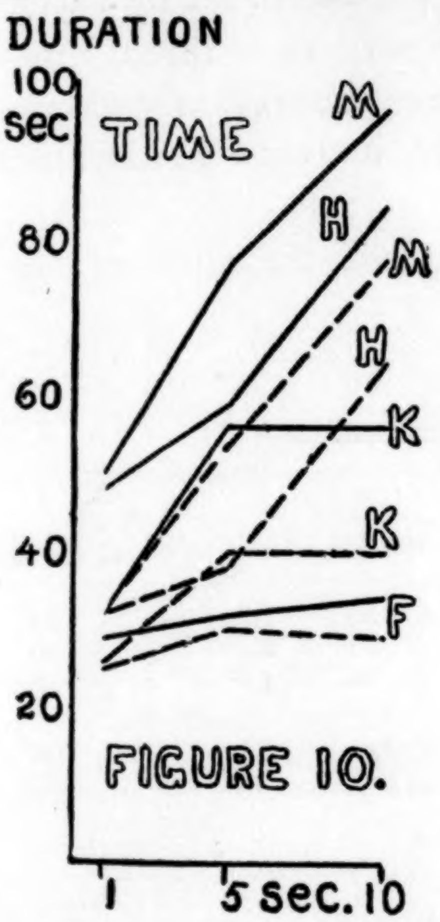


FIGURE 10.

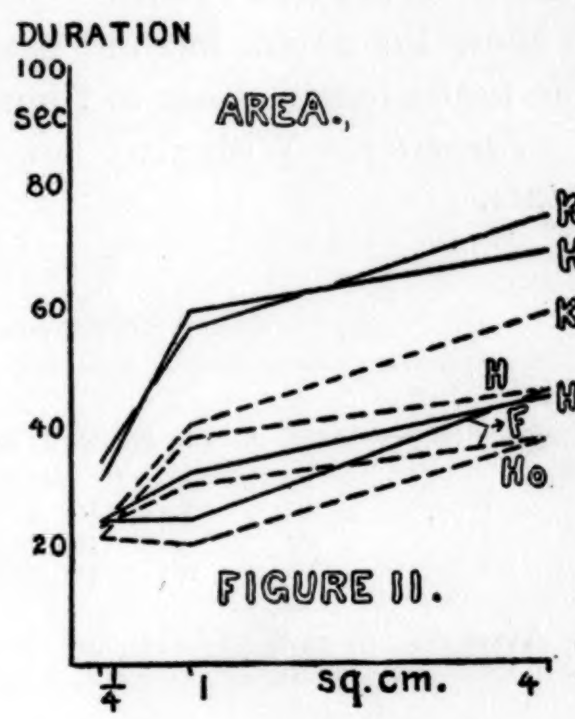


FIGURE 11.

The corresponding series in Miss Seebring's experiments show the following results for the total time of duration:

TABLE XI.

Time of stimulation.	3			15			60		
	Aver.	A Var.	No. Exp.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.
First series.	21	9	5	47	6	5	107	5	5
Second series.	23	4	5	43	6	5	101	7	5
Averages.	22		10	45		10	104		10

Full records of the fluctuations were taken only for the second series, and the actual time that the image was seen can

be given only for these experiments. The following table shows the relation between the total and the actual duration:

TABLE XII.

Time of stimulation.	Total time. Aver.	A. Var.	Actual time. Aver.	A. Var.	No. Exper.
3 sec.	22.6	4.	10.9	3.9	5
15 sec.	42.6	6.	36.	4.4	5
60 sec.	101.2	7.	98.6	8.4	5

In Titchener's results the same effect is noted. The varied intensities and areas do not permit, however, of a direct comparison of the three series. But they have enough in common to show the rapid, but not proportionate, increase in duration due to the longer times of stimulation.

Intensity.—With 1 sq. cm. and 5 seconds exposure as constants.

TABLE XIII.

TOTAL DURATION OF AFTER-IMAGE.

Intensity in c.p.	.01			.1			1.0		
Subjects.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.
K.	40	12	20	56	24	20	70	19	20
H.	29	9	10	59	15	10	84	19	10
F.	26	6	10	32	5	10	50	3	10
Average.	31.8		40	49		40	68		40

TABLE XIV.

ACTUAL DURATION OF AFTER-IMAGE.

Intensity in c. p.	.01			.1			1.0		
Subjects.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.
K.	28	6	20	40	12	20	52	9	20
H.	22	7	10	38	17	10	63	18	10
F.	25	3	10	30	5	10	50	3	10
Average.	25		40	36		40	55		40

Using a cross with 1 sq. cm. arms and 15 seconds exposure, Mr. Southack found for himself and a second observer the following results. The standard intensity, 1, was a 100 c. p.

incandescent lamp at a distance of 30 cm. from the ground-glass cross. The varying intensities were obtained in the usual manner.

TABLE XV.

TOTAL DURATION OF AFTER-IMAGE.

Relative Intensities.	1/320			1/64			1/4			1		
Subjects.	Av.	A. Var.[1]	No. Exp.	Av.	A. Var.[1]	No. Exp.	Av.	A. Var.[1]	No. Exp.	Av.	A. Var.[1]	No. Exp.
A.	8	5	20	10.6	1.5	20	11.2	1.7	20	60.7	10.7	20
B.	11.8	1.4	10	14.4	3.2	10	18.1	1.9	10	26.4	1	10

Area: constants, 5 sec. and $\frac{1}{10}$ c. p.

TABLE XVI.

TOTAL DURATION OF AFTER-IMAGE.

Area of Stimulus in sq. cm.	1/4			1			4		
Subjects.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.
K.	34	15	20	56	24	20	74	24	20
H.	31	12	10	59	15	10	68	17	10
Ho.	24	3	5	24	4	5	45	15	5
F.	24	8	10	32	5	10	44	6	10
Average.	28		45	42.8		45	57.8		45

TABLE XVII.

ACTUAL DURATION OF AFTER-IMAGE.

Area of stimulus in sq cm.	1/4			1			4		
Subjects.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.	Aver.	A. Var.	No. Exp.
K.	23	7	20	40	12	20	58	10	20
H.	21	10	10	38	17	10	45	9	10
Ho.	21	3	5	20	5	5	37	11	5
F.	23	5	10	30	5	10	37	11	10
Average.	22		45	32		45	45		45

The increase in duration for the greater intensities and the longer times of stimulation is easily explained on purely physiological grounds. In both cases more of the photo-chemical matter

[1] The average variation of the averages when the experiments were grouped in sets of five. This was the only calculation left by Mr. Southack. The records of the individual experiments could not be found.

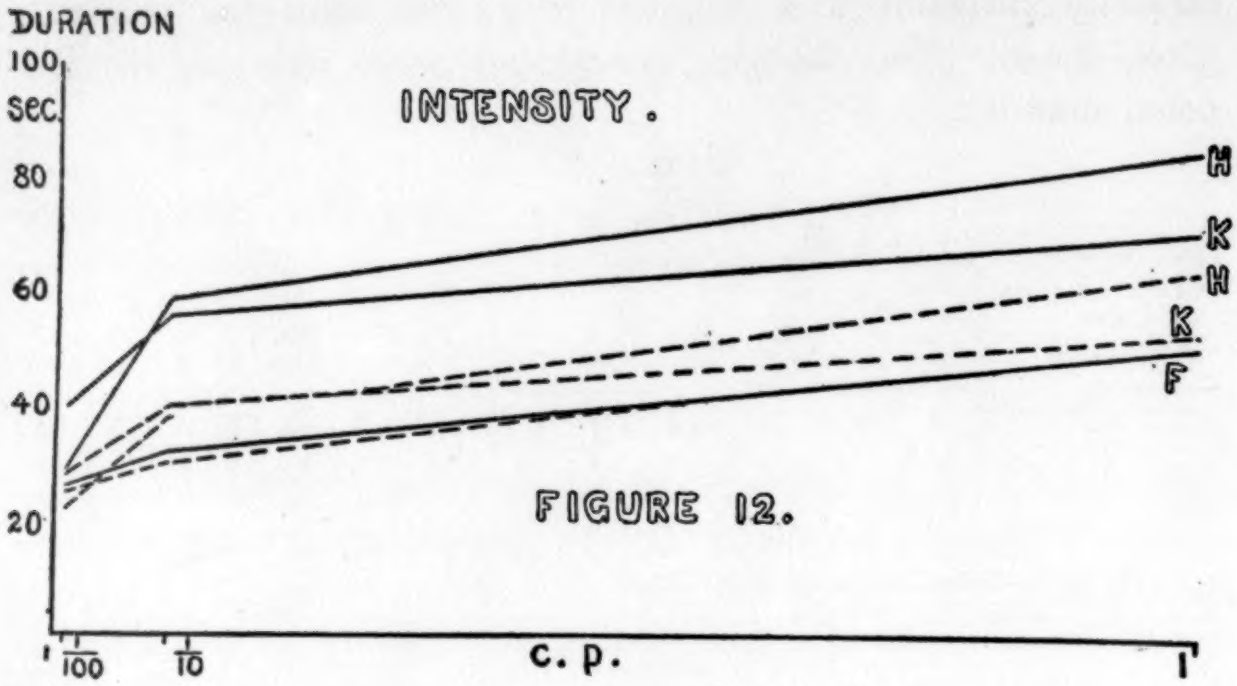


FIGURE 12.

of the retina may be decomposed, and it takes the retina longer to come to a state of equilibrium. The effect of the larger areas, however, cannot be explained by such a simple process. In the latter case there is only an increase in the number of retinal elements stimulated, and not a greater stimulation of any one element. An explanation of the greater durations with the large areas must probably be looked for in another direction. In the threshold experiments the same effect was noticed, and it was concluded that the cause was mental. In this case, when the after-image is fading, a small light is hard to notice, and the large one, with its numerous points for the shifting of the attention, is easy to keep in view. The different durations for the large and the small areas is, accordingly, only an apparent one.

The relative effects of the physical units are shown in the accompanying curves, which are constructed from the averages of subjects H, K and F. The results from these three observers only were used because a slight variation due to the fourth subject would disturb the common point of coincidence in the three series. Fig. 13 represents the results of actual time of the after-image, while Fig. 14 shows the results for the total time.

Such a simple relation as was found in the threshold experiments between the units of physical energy seems not to

hold here. This is not surprising when it is considered that the longer time that the image is in view gives greater opportunity for outside influences to affect the process.

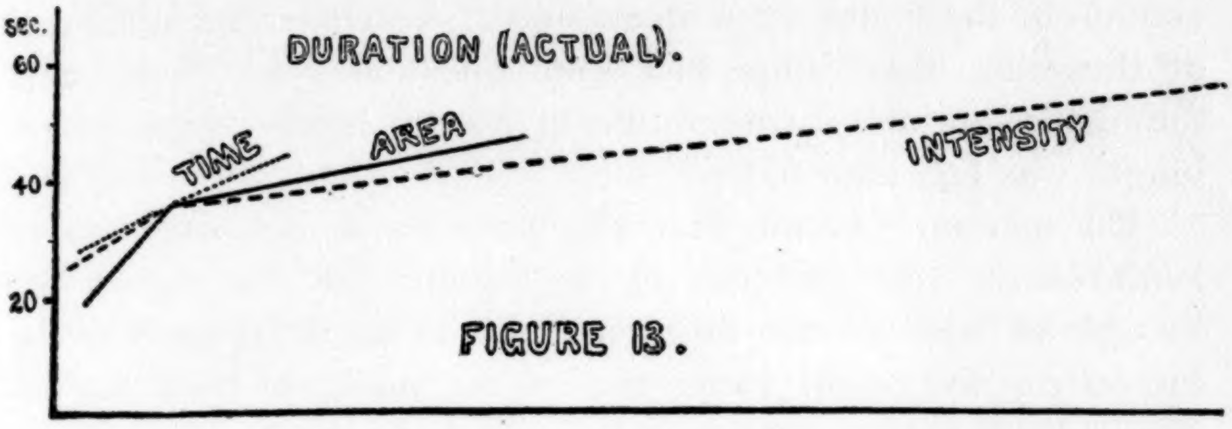


FIGURE 13.

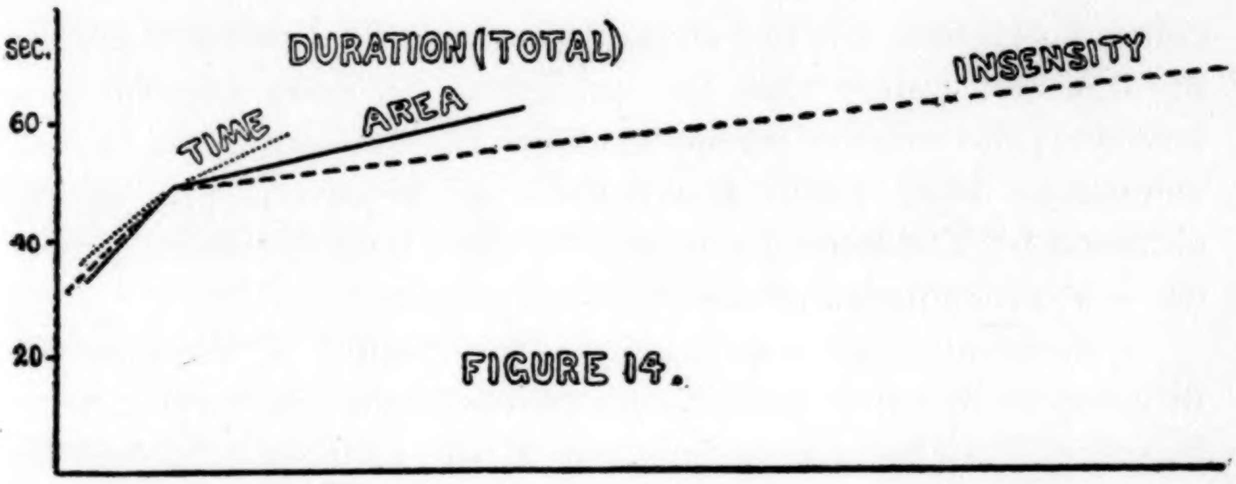


FIGURE 14.

The constancy of the relation of the actual to the total duration should be noted. The average proportion is 76 : 100, while the variation for this is about 3.

Quality of Light.—If a spectrum projected on a wall is looked at for some time and an after-image obtained therefrom, it will be noticed, besides the qualitative differences, that the image of the central portion, the yellow and green parts, lasts relatively longer than that of the red or violet ends. This has sometimes been considered as evidence that the central portion of the spectrum is of greater intensity than the ends. This hypothesis seems at first sight to be the correct one; but at times it has not been sufficiently considered by investigators.

Bidwell[1] notes that while the after-image obtained from the

[1] Op. cit., p. 140.

whole spectrum was violet, he could get no after-image from the red and the violet of the spectrum. This fact he attempts to explain without considering the intensity differences, and he uses the observation to prove that the image is due to an excitation of the violet nerve-fibers only. However, the accuracy of Bidwell's observation has been questioned by Hess, who found that an image was produced by red lights whose wave-length was less than 623 μ.

Charpentier[1] found that the *persistance des impressions rétinniennes* was affected by the quality of the light; but though he believed the difference due to the differences in the intensity of the stimuli rather than to the quality of the light, his results were not reported in full.

In his work with transmitted light, Titchener[2] used various colored gelatins, which resulted generally in showing a longer duration for yellow than for red light. In these experiments, however, the relative intensities were not the same, and in this connection little value attaches to the results. The results obtained by Titchener for effects of other colors—violet, green, etc.—are incomparable for the same reason.

I have attempted to exclude the factor of illumination-differences by using gelatin films whose absorbent powers were known. The light was so arranged for each gelatin that the intensity was equal for all. The following table shows the results for stimulation of 5 seconds and an area of 1 sq. cm.:

TABLE XVIII.

	V.	B.	G.	Y.	O.	R.
Duration in seconds.	24	26	30	24	27	22
A. Var.	6	5	3	5	7	6

Ten determinations were made with each kind of light. On the first line will be found the average duration under the various conditions; and below, the average variations for each series of experiments. It will be noticed that practically no

[1] *C. Rend. de la Soc. de Biol.*, Sér. 8, Vol. IV., p. 92, 1887.

[2] Op. cit.

difference is found to exist between the after-image-producing power of any colors. The variations make an overlapping of the times in such a way as to show that the slight differences noticed at first in the table are only apparent.

In this connection it would be interesting to test individuals who are partially or totally color-blind. Tests on such a class would probably be the only valid ones as indicating the part played by the quality and by the intensity of the light.

Parts of the Retina.—Purkinje, Aubert and Exner have noted independently that light-sensations continued longer in the fovea than on the periphery of the retina. These observations have been disputed by more recent investigators, however. The experiments, dealing only with the phenomenon of visual persistence, do not indicate what might be expected for other similar phenomena, particularly the longer continuations, such as after-images. In view of the fact that we can see less clearly with the peripheral portions of the retina,[1] and that these parts are more easily fatigued,[2] it seemed probable that the after-image would also be less distinct and would continue a shorter time. The supposition was proved correct by the results of the experiments.

Each of seven points along the inner side of the right eye were stimulated with a stationary light, and the total and the actual times of duration of the after-image were noted. As stimulus, I used a small lamp with an intensity of about ½ c. p.

TABLE XIX.

Angular distance from fovea.		0°	15°	30°	45°	60°	75°	90°
Total	Aver.	40	32	10	0?	0	0	0
Duration	A. Var.	8	9	4	—	—	—	—
	No. Exp.	10	10	10	5	5	2	2
Actual	Aver.	35	24	8	0?	0	0	0
Duration	A. Var.	7.5	9	5	—	—	—	—
	No. Exp.	10	10	10	5	5	2	2

[1] See Aubert, Grundzüge d. Physiol. Optik, 1876, p. 539 ff.

[2] Ibid., p. 545.

This was looked at for about 5 seconds, and the angular distance subtended was about two degrees. The light was at all times at a constant distance from the eye (retina), viz., 30 cm. The table on page 29 shows the results of the experiment upon each of the points, 0° being the fovea.

Not only were there differences in the duration of the after-image, but the fainter appearance of a sensation toward the periphery was duplicated in the after-images. No variations in color of the after-image corresponding to the different points tested was apparent.

This gradual, but finally absolute, lack of ability to distinguish an after-image is probably due to several factors. Aubert mentions that the periphery is more easily fatigued than the fovea; but he does not seem to consider that this may be partly mental and not entirely physiological. From observations made during the progress of the experiments it seems likely that the inability to attend to these things not in its immediate vicinity is the primary reason for the lack of images toward the periphery, and for the long durations at the fovea. At 45° it was felt at times that an image might be present, but so indistinct that it was impossible to give any definite answer. In the table these results are accordingly given as 0 (?).

A similar but more extended set of experiments upon the quality as well as the duration would be important for testing color theories, but this point of view was not considered till the present series had been finished.

Individual Differences.—Throughout the foregoing pages one or more individuals have been considered as giving typical results. That this is not strictly true, however, has been fully recognized; and from the material at hand I have endeavored to discover some of the individual conditions upon which the duration depends. The numerous difficulties in such a study are evident: each individual is not the same at any two moments, and various distracting thoughts cannot be excluded.

During the past few years there has been made at the Columbia laboratory a series of mental and physical tests. Among these was one on after-images, in which the duration, the color, etc., were noted. One great defect of these measurements is to

be found in the fact that there were many experimenters instead of one, making methods of experimenting and of recording to some extent dissimilar. In general, however, the results are fairly comparable, and are as accurate as the method of correlation used in this case. The individual differences of recording had little influence upon the measurement of the total time; but by some the actual time with the various fluctuations were not given at all. For this reason only the total time can be used as a basis for comparison.

The stimulus was a cross, with arms 1 sq. cm., illumined by a 100 c. p. incandescent lamp in a box. The lamp was 30 cm. from a plate of ground glass, which was used to make the cross of uniform brightness. The subject was seated in a semi-dark room, and no adaptation time was needed. The cross was shown for ten seconds and then shut off by a screen. The subjects, having closed and covered the eyes without pressing upon them, informed the experimenter of the various phases as they occurred, and these were recorded as well as possible. Generally two trials were given.

The tests chosen for comparison with the results of the after-image test were sharpness of vision, color-vision and imagination-type. These were so chosen because they seemed closely allied to, or were thought to have an influence upon, the after-image. It would have been interesting to compare, in addition, visual and auditory memory, time of reaction to visual and to auditory stimuli, etc.; but at that time such tests were not included in the anthropometric series.

Sharpness of vision was tested with the Galton eyesight-tester. This is an instrument having at certain distances cards of numerals in diamond type which are to be read by the subject, who looks through a hole in a screen. The type was illumined by a 100 c. p. incandescent lamp at a distance of one meter from the card, which was 37 cm. from the eyes. The normal distance for reading correctly eight or more out of ten numerals was for each eye 42–52 cm.

Color-vision was tested with spools of colored wools; but this, being only a rough-and-ready method of detecting color-blindness, did not show defects which did not amount to blind-

ness. Only six color-defectives were found, and their after-images may be paralleled by numerous other observers who were considered nearer normal. The results, accordingly, show no unusual variations.

The imagination-type was discovered by means of the following series of questions, part of which are the classic ones of Galton: Think of your breakfast-table as you sat down to it this morning; call up the appearance of the table, the dishes and food upon it, the persons present, etc. Then write answers to the following questions: Are the outlines of the objects distinct and sharp? Are the colors bright and natural? Where does the image seem to be situated? In the head? Before the eyes? At a distance? How does the size of the image compare with the actual size of the scene? Can you call to mind better the face or the voice of a friend? When violin is suggested, do you first think of the appearance of the instrument or the sounds made when it is played? Can you call to mind natural scenery so that it gives you pleasure? Music? The taste of fruit? Have you ever mistaken a hallucination for a perception; *e. g.*, apparently heard a voice or seen a figure when none was present?

Of the subjects who answered the questionnaire, 59% would be considered as of a distinct visual type, 4½% were distinctly auditory and 36½% would be considered of mixed type.

For comparing these results with the duration of the after-image, only the simple method of correlation was used. The results of the subjects that were considered as having hypernormal, normal or subnormal vision were grouped and the average duration of the after-image was calculated; a similar method was used for the imagination-type correlation. This method is not above criticism; but it is sufficiently accurate to show certain tendencies and influences. The results for the accuracy of vision in the right and left eyes, and for the type of imagination, are summarized in the following tables.

Objection may be made to this method of correlation, to the grouping the subjects and the use of one or, at most, two experiments, as giving a typical value for the individual. The objections would apply to all anthropometric series, and it has weight only when one attempts to apply results to individuals.

It is only in considering an individual as of a class that the figures have a value.

TABLE XX.

Acuteness of vision, right eye.	No. of cases.	No. of exper.	Av. durat. of after-image in secs.	Av. var.	Percentage of times no image was seen.
0–37 cm. Subnormal.	37	57	26		49
44–52 cm. normal.	63	92	37		27
61–85 cm. Hyper normal.	35	59	37		25

TABLE XXI.

Acuteness of vision, left eye.	No. of cases.	No. of exper.	Av. durat. of after-image in secs.	Av. var.	Percentage of times no image was seen.
0–37 subnormal.	37	57	32		46
44–52 normal.	76	106	34		26
61–72 hyper normal.	26	42	36		26

TABLE XXII.

Mental Type.	No. of cases.	No. of exper.	Av. durat. of after-image in secs.	Av. var.	Percentage of times no image was seen.
Visual.	77	121	36		26
Mixed.	47	65	37		32
Audile.	6	8	16		63

Probably the most interesting fact to be noted in the tables is not that the duration is longer for the visual type, or for the man with strong eyes, but that in these classes the total number of times when no image was noticed is small compared with the percentage for the audible type, or for those having weak eyes.

Granting that these variations are true criteria of the different classes, an explanation must be sought. It is easy to see why an individual of a visual type might have an after-image of longer duration than one of an audile type. Accustomed, as he is, to note principally those phenomena which appeal to his eyes, practice enables him to select the visual stimuli and to attend to these even if of little intensity. Accordingly, an after-image in its final stages, when very dim, would be noted by

him; whereas an auditory type of individual might neglect this minimal amount of sensation. A similar hypothesis would explain why audiles should see less images than visuals. Many of the images are undoubtedly of little intensity, and they would be unnoticed by those individuals unaccustomed to note small visual differences. This would reduce the differences to a question of the attention or of habit, rather than to a physiological process; and this explanation is in accord with what was noted above in the experiments upon the increase in the area of stimulation.

In a similar series made upon a class of seven boys by Dr. F. B. Brandt this explanation is further confirmed. Using a stimulation of 1 sq. cm. of the northern sky fixated for 15 seconds at a distance of 30 cm., Dr. Brandt found that those boys who held the highest rank in school-work, those who had learned to fix their attention, could see the after-image for a longer time than those who were dull and inattentive. The attention in this case may have been largely influenced by 'interest,' but the general result and conclusions are the same. The 'bright' boy is he who is interested in each novel experience; is he who attends with all his might to what is immediately present. During the course of the experiments this view was clearly indicated by a study of the actions of the subjects. A and B had been intellectual rivals throughout their school-work, and when B found that A was having after-images of longer duration than he, his interest flagged and it was difficult to persuade him to continue. While there are some variations in the relation between scholarship and the duration of the after-image, the results show that the three boys of excellent ability very easily outrank the other four. The following table gives the results of ten experiments upon each subject.

In conjunction with the attention, imagination undoubtedly plays an important rôle in these phenomena. Miss Washburn has noted that she was able to control voluntarily the colors of the after-image;[1] and in addition she mentions that when she visualized a color and tried to force the after-image to take this quality,

[1] M. F. Washburn, Subjective Colors and the After-image; *Mind*, N. S., VII., 25-34, 1899.

TABLE XXIII.

Subject.	Scholarship grade.	Duration of after-image in seconds.	Average variations.
A.	96%	320	36
B.	95	169	64
C.	92	267	65
D.	82	60	26
E.	81	69	51
F.	80	135	40
G.	79	42	31

'the image of the visualized color was brought on sooner,' and 'held longer than usual.' Miss Washburn concludes, as I do above, that the image is largely influenced by the attention, and that perhaps the imagination is to be explained as the calling the attention to any part of the image; the color is there, but it remains unnoticed till we are prepared for it. In this way the after-image would also appear to be in view a longer time.

Miscellaneous.—Besides these factors, other influences affect the duration of the phenomena. Helmholtz [1] noted that if an electric current be sent through the eye and the optic nerve, the image is changed in character and the time of duration is (probably) shortened. This change is analogous to that occurring when the eye is stimulated with light while an image is in view. Exner [2] found that the retinal circulation and pressure on the ball of the eye influenced the duration. Brewster [3] in 1834 noted that a smart blow on the head would stop an image in its course. Similar results were obtained from my subjects, but sometimes the image would also seem of less intensity. In the morning, when the eyes were fresh, the image lasted about 30% longer than in the evening or when fatigue was apparent.

All these factors may be resolved into an influence of the attention on the one hand, or of the physiological process in the sense-organ on the other. Either explanation would suffice; but it seems that both should be considered. In conjunction

[1] Physiol. Optik, 509.

[2] Ueber die Funktionsweise d. Netzhautperipherie und den Sitz der Nachbilder; *Archiv f. Ophthal.*, XXXII. (2), 233–252, 1886.

[3] Accounts of Two Experiments on Accidental Colors; *Philos. Mag.*, 3 Ser., IV., May, 1834.

with the material of the foregoing paragraphs it seems likely that the mental element is very great—that is, the blow on the head or the general fatigue, the pressure on the eyeball, etc., are influences inhibiting the focussing of the attention upon the after-image. Particularly is this the case when these factors are brought in in an artificial manner that their effect may be observed. Voluntary winking, where the attention must be turned away from the sensation to the movement, shows the same effect.

When the stimulus was not attended to, when the subject was distracted with a continued conversation, while all distracting influences ceased with the end of the stimulus, the duration and the intensity of the after-image seemed not affected. When however, distracting sensations, sounds and conversation were introduced during the progress of the after-image the attention was distracted sufficiently to cause an apparent shortening in the duration of the after-image by about 40%.

Summary.—The after-image, particularly in its duration, if affected by many mental and physical conditions. The most influential of these seems to be the mental attitude of the subject. If he looks intently for the after-image, if he is accustomed to note visual changes, the image will apparently remain longer than if his attitude is more motor or auditory. When the attention is directed in its greatest intensity to the after-image, either from habit, because one is visual-minded, or voluntarily, the duration is about one-third longer than when the attention is not so directed. Various physical conditions—*e. g.*, having the image on the periphery of the retina, physical fatigue, etc., which give similar results—may also be considered in this class. Of the physical light-changes, the most influential seems to be the time of stimulation. This corresponds to what was found in the experiments on the threshold and latent period. The area- and intensity-changes also have effects similar to what was found in the experiments upon threshold and latent period; but no general relation of these effects seems to be discovered. Figures 13 and 14 show composites of the average results from Tables IX.–XVII., and from them the relative effects of the physical units may be noted. Contrary to

the generally accepted view, variations in quality (color) seem to have little effect unless there is, as usual, a change in intensity.

SECTION 5. FLUCTUATIONS.—In all discussions of the after-image one of the questions that has been largely neglected is that regarding the fluctuations from positive to negative, its disappearances and reappearances. Immediately upon the close of the stimulus an after-image due to the continuation of the light is seen. A vacant period (the latent time, see Sec. 3) follows, and then an image which in turn fades away into another color or disappears and reappears several times. This fluctuation was noted by R. W. Darwin,[1] and has been variously ascribed to many physiological causes connected with the sense-organ—to eye-movements, to winking, to pressure on retina, etc. During the progress of the present work I endeavored to note the various effects of these conditions. Most of the experiments were made in a dark-room, and the image was looked for with eyes open. Pressure on the eyeball was thus prevented, but the fluctuations continued. Winking, if unconsciously done, disturbed the image momentarily, but had no lasting effect. However, if consciously done (*i. e.*, when the attention was directed away from the after-image to the movements of the eyelids), the image seemed lost for an appreciable time. The numerous involuntary eye-movements could not be controlled. The eyes tended to *follow* the image, which would remain in view while these movements were not inhibited. If consciously prevented, if the eyes were brought back to what appeared to be their normal position, if the eyes were consciously rotated while the phenomena lasted, the image would disappear, only to reappear if consciously brought back—*i. e.*, if the attention was again directed to the organ of sensation rather than to the movements of this organ. From these observations of my subjects and myself I am inclined to believe many of the fluctuations are mental in character, just as we have seen the duration to be largely a mental matter. In other words, the various

[1] R. W. Darwin, New Experiments upon the Ocular Spectra of Light and Colours; *Phil. Trans.*, LXXVI., 313-348, 1786.

phases are influenced more by the mental attitude of the subject than by the physiological condition of the retina.

Helmholtz noted that violent movements of the body changed the character of the after-image from positive to negative,[1] and that an electric current sent through the optic nerve changed the intensity of the after-image present.[2] This may also be seen to agree with the attention hypothesis.

In some respects the fluctuations of the image arising from stationary stimuli are analogous to those noted by Bidwell[3] and by Charpentier.[4] However, the images noted by these investigators were so complex that it seems uncertain whether we are dealing with the same phenomena. The Bidwell recurrent images are explained satisfactorily upon physiological grounds; but in repeating the experiments I was led to believe that at least the brightness of the various bands was due in large measure to the fixation of the attention.

The changes in the physical stimuli seemed to have no effect in the present case. The after-images when they lasted longer did not have more fluctuations, but the various phases remained for longer times. Such a great variation in the number and in the character of the fluctuations was noted that it seemed impossible that any general relation held true. Opposed to these results, however, are observations by Helmholtz[5] and by Miss Washburn.[6] Helmholtz noted that the duration of the stimulus had an influence upon the negative as well as upon the positive phases; but he only makes this general statement without further detail. Miss Washburn also observed variations in the fluctuations due to intensity-changes of the stimulus.

SECTION 6. QUALITATIVE CHANGES.—As one of the most difficult and most striking of the phenomena to be explained, the color-changes of the after-image have attracted a great amount of attention. But throughout the various accounts of the color-changes it seems to have been assumed that the experimenter was normal, and what occurred in his eyes would or

[1] Physiol. Optik, p. 504.
[2] Ibid.
[3] Op. cit.
[4] Op. cit.
[5] Op. cit., p. 505.
[6] Op. cit., p. 27.

should occur to another, if he saw the same light. This belief has led in some measure, I fancy, to the disagreements regarding the phenomena. The individual element seems not to have been considered by any one. In the experiments noted in Section 4 it was found that the various observers differed greatly in their account of the color-changes; and, moreover, an individual did not always see the same colored after-image when stimulated with the same light. At one time, all the images would be seen as light alone, at another, they appeared gray or reddish. This change appeared with all my subjects. The difference was also noted by R. W. Darwin,[1] who considered the changes as due to his making too many experiments at one time, his eye being 'not quite free from the spectra of the colours previously attended to.' The difference of individuals is naïvely noted by Miss Washburn in her recent paper. In this paper she says her subjects had to be ***drilled to see a normal image*** (*i. e.*, like her own).[2]

From the after-image experiments in the series of anthropometric tests (see Sec. 4), it was found that "the after-image, when first seen, was sometimes positive and sometimes negative: and the colors varied greatly, being distributed in the first place as follows: negative or dark, 33%; light or white, 29.4; blue, 13.7; purple, 9.8; green, 5.9; yellow, 3.9; red, 2.0; miscellaneous, 2.0."[3]

Various trials were made of physical conditions to discover whether or not the change was due to these; but for the conditions tested (position of eyes in relation to light, accommodation, adaptation, changes in intensity, duration and area of stimulus), nothing definite was discovered.

Fechner found that various durations of the stimulus gave different colored after-images, but I found no such definite relation with the comparatively long times used by me. The change in quality of the after-image under any one condition—*e. g.*, 5 seconds—seemed as great as that observed between 5 seconds and 1 second stimulation. The only uniform change

[1] Op. cit.

[2] Op. ct., p. 27.

[3] Cattell and Farrand, Physical and Mental Measurements of the Students of Columbia University; *Psycho.. Rev.*, III., 618–648, 1896. See especially p. 645.

noted was that with the greater intensities and the longer stimulations the after-image appeared oftener as negative. With medium intensities such as I used this result is almost never noted; but the change is clearly brought out in the results of the experiments upon threshold (where only $\frac{1}{6}$ of 1% were negative) compared with the results upon duration (where fully 80% of the images had negative phases).

The quality (or intensity) of the image was changed by Helmholtz by sending an electric current through the eye. "If one has developed in the eye a negative after-image and then sends an electric current through the eye and the optic nerve, * * * the negative after-image becomes darker, and if an image is just on the borderland between positive and negative, it can be made negative by sending a current through the eye."[1] This change is somewhat analogous to what occurs when an after-image is produced and external light is then admitted to the eye.

I can attempt no explanation for these individual differences. The suggestion has been made that the differences may be due to a varied sensitiveness of the retina to light-waves of different lengths. Such an explanation seems, however, too hypothetical when one considers the great differences. One subject saw the after-image always as green; to another it was always red; to a third it varied in the white-black series. The explanation could not be stretched in any case to cover the change in an individual under practically the same conditions. The importance of these differences for theories of color-vision will readily be recognized. If later experiments are made, a most careful study of each subject's color-vision should also be made.

The control of the color of the after-image should again be noted. Miss Washburn attempted to control the color-changes, but concludes that the control is not real, but apparent. In her case the attention intensified certain colors that were present, but which would be unnoticed under ordinary circumstances. Such an explanation of the effects of attention probably could not be made to include the variation of one individual from another. The problem needs more detailed and careful study.

[1] Op. cit., p. 509.

An attempt to change voluntarily the character of the after-image from positive to negative has been uniformly unsuccessful in my own case; Miss Washburn seems to indicate that this was done by all her subjects, and it may be that being a poor visualizer accounts for my inability.

SECTION 7. SPACE-RELATIONS.—In his characterization of the difference between after-images and the images of the imagination, Fechner considers as one of the greatest differentia the spatial character of the phenomena. The after-image is, according to him, of two dimensions only, while the images of the imagination are tridimensional. This statement has not often been disputed, but there seems little truth in it as a statement of universal fact. Professor Hyslop found that if a "picture hanging obliquely on the wall, say thirty degrees, more or less, and I look at it while lying on a bed or lounge and then look at the wall vertically near me,* * * I notice that the after-image *does not lie in the plane of the wall, but in the same position relatively to the plane of vision as in its real position.*"[1] In other words, we have here a case where the after-image was distinctly opposed in character to what Fechner said we have it.

In view of these contradictory statements, it seemed advisable to test the matter more thoroughly, using several subjects. A few simple experiments were devised for the purpose. The subjects, naïve as to the purpose of the experiment, were asked to gaze fixedly for fifteen seconds at one corner of a highly colored rectangular block, and to project the resultant after-image upon a white wall about four meters distant. Note was to be made of size, color, etc., but no suggestion was given regarding the tridimensional character. Throughout the experiments the eyes were open. A brightly lacquered round resonator, two brightly colored books placed like a V with the apex turned away from the subject, and two incandescent lamps placed at different distances from the eyes, were also used as stimuli. Some of the observations with the various stimuli are as follows:

[1] J. H. Hyslop, Experiments in Space Perception; *Psychol. Rev.*, I., 588, 1894.

"Projected from the wall, but not distinctly."

"Seemed to stand back. Solid."

"Some suggestion of solidity, but no definite outline."

"Perhaps (?) solid."

"Vague feeling of projection from wall."

Most of the results, however, seem negative. With closed eyes, on the other hand, the image became more nearly like the imagination-images; and while there was a feeling of insecurity, the images acquired the tridimensional character of the mental products. This may be due (in some cases it was due) to the superposition or to the strengthening of the after-image by the imagination-image. Here we must also consider the effects of the attention. We ordinarily see what we wish to see, and the numerous questions regarding the space-relations may have tended to suggest to the subjects the answer sought. With some subjects, however, no amount of experiments or suggestions could get them to say anything beyond that the image seemed '*almost* solid.'

If my own attitude is to be considered typical, I should say that the image appears at first distinct only in outline. The differences of light and shade which we note in the original solid object do not appear in the after-image till we look for them, and then it is difficult to say whether the differences are really due to the imagination or whether they are in the after-image. The time it took many of my subjects to note the third dimensions would indicate that this space-character was 'read into' the sensation rather than given.[1] This much, however, seems clear, that if there is any appearance of solidity connected with the after-image, it is not nearly so evident as it is in sensation or in imagination. The fact that the image is projected by us into space, and is there localized, leads one to believe that the idea of depth is not wholly wanting in the ordinary after-image. This would seem to class the phenomena rather as perceptions than as sensations.

[1] Professor Hyslop advises me that almost seventy-five per cent. of the students in his introductory classes fail to perceive at once the third dimension in stereoscopic pictures. Many succeed after the suggestion has been given, but some fail to obtain the usual result even after many experiments.

Stereoscopic experiments, in which the sensation was one of solidity, gave no indication of apparent solidity in the resultant after-image.

The size of the image, as is well known, apparently increases or decreases if we look respectively at a far or at a near object. This apparent change in size is due to the fact that a certain portion of the retina is concerned with the seeing of any after-image, and the amount of space subtended by this portion of the eye increases as the square of the distance of the wall or screen. When projected on the same screen the size of the after-image from any light is approximately constant for all observers; the few variations noted are probably due to hasty judgments or poor observations. It may be that the moving of the eyes during the stimulus produced in these cases a larger image, more of the retinal elements having been stimulated. A curious fact in connection with the apparent change in size is that if a long image is projected upon a receding wall one end is seen wider than the other. A more wonderful and more puzzling phenomenon is mentioned by James. If an after-image is projected on a flat surface 'resembling a receding screen,' the image takes on the form it would have if seen under similar actual conditions just noted. Such a result points strongly to mental influences, which we have seen are important factors in all conditions of the after-image, viz., attention and imagination. The experiment makes it evident that the phenomena are closely related to the imagination and to perceptual processes. The experiment was repeated by several of the subjects, but at first all united in affirming no such change. The suggestion made, however, to one individual gave the effect. It is impossible to tell from James' remark whether the observation is original with him or whether it is quoted.

To discuss the apparent size of the after-image seen when the eyes are closed leads one into all the difficulties that have followed the discussion of the moon's size. It is interesting to note, however, that when asked the size of the image resulting from a cross with arms one decimeter square as viewed at a distance of three meters the average of the sizes noted by

observers was 7.5 cm. and the image was said to be about 1.87 m. from the eyes. The variation is large and the individual answers show characteristics of the several observers. The subject might repay fuller and more extended observation.

SECTION 8. THE RETINAL TRANSFER OF THE AFTER-IMAGE.—One of the questions of considerable interest raised by Newton in his letter to Locke was that regarding the transfer of an image from the stimulated to the unstimulated eye. "Though I looked with my right eye only" (at the sun), he says, "and not with my left, yet my fancy began to make an impression upon my left eye as well as upon my right. * * * With my left eye I could see the spectrum or the sun almost as plain as with my right."

Brewster[1] independently noticed the phenomenon, and it has been discussed fully by many observers, notably by Helmholtz, Fechner, Charpentier and Titchener. A complete discussion of previous views will be found in Titchener's[2] article, and only a brief résumé of the general views need here be given.

It will readily be seen that the transfer may be explained in any of the following ways: (1) The appearance is an extension of the well-known phenomena of binocular contrast. (2) There is a functional connection between the retinæ, whereby one is affected by what affects the other. (3) The after-image has its seat in the brain, and not in the retina. (4) The transfer is only apparent.

Fechner[3] and Helmholtz[4] are the sponsors of the first theory. The former stimulated one eye with a bright-colored light, and the other was darkened or stimulated with a very weak gray light. According to him, the unstimulated eye saw the contrasted color during the continuation of the stimulus, and this left its effect (a true after-image, apparently) in this eye. In other words, the after-image was not transferred, but the op-

[1] Article on Accidental Colours, in Edinburgh Encyclopedia.

[2] E. B. Titchener, Ueber binoculare Wirkungen monocular Reize; *Philos. Stud.*, VIII., 231–310, 1893.

[3] Fechner, G. Th., Ueber einige Verhältnisse des binocularen Sehens; *Abh. d. k. Sach. Ges. d. Wiss.*, VII., 481, 1860.

[4] Op. cit.

posite nerve-fibers of the unstimulated eye were excited during the progress of the sensation, whence an after-image was produced. This explanation, accordingly, is only a different form of the next theory.

In support of the co-excitation hypothesis many other physiological phenomena may be cited. The most evident of these are the facts that both eyes are used as a single instrument; that they are moved together; and that if one eye is in the dark while the other is in light, the iris of the former will expand as the iris of the latter does. Similar other points indicate that the two eyes are controlled as one. Charpentier[1] is the main exponent of this theory; but his experiments upon the varied sensitiveness of the two eyes do not seem to have been well chosen or conclusive.

Parinaud,[2] Ebbinghaus[3] and Binet[4] are supporters of the third explanation. Almost the same experiments that convinced Fechner and Charpentier were used by them in making the new hypothesis. It is taken for granted that the image is seen by the eye that is open, and to them the only satisfactory explanation is that the image lies in the cerebral center of vision, and not in the retina.

While accepting the same general point of view, Titchener introduces a new series of experiments to prove that the transfer is real, and is not an apparent one. The experiments included observations upon (1) the relative duration in the stimulated and in the non-stimulated eye; (2) the variations in the fluctuations; (3) the color-changes, and (4) the differences in brightness. The results of these experiments by Titchener are summed up as follows: (1) The image in the non-stimulated eye lasts a shorter time than in the stimulated eye. (2) The relative time which the two phases of the secondary (*i. e.*, in the non-stimulated eye) image take is in no way similar in the primary eye. (3) The phenomenon occurs also under conditions when a mix-

[1] Charpentier, A., La lumière et les couleurs, Paris, 1888. Sur les connexions fonctionnelles des deux rétines. *C. Rend. de la Soc. de Biol.*, 8 Ser., II., 364, 1885.

[2] *C. Rend. de la Soc. de Biol.*, 13 May, 1882.

[3] *Archiv f. die gesammte Physiol.*, XLVI., 498, 1891.

[4] La Psychologie du raisonnement. Paris, 1886, p. 45 ff.

ture of both fields of vision is made impossible. (4) There is a constant difference in brightness between the negative complementary images in the two eyes. (5) Experiments upon a monocularly color-blind person gave evidence of the second image.

On the other side of the question we find Delabarre. To him the secondary after-image is an illusion; the transfer is only apparent. Considering the experiments made by Parinaud and Binet, he says: "A serious difficulty in settling the question lies in the well-known impossibility of separating the visual fields of the two eyes. Whether one eye or both are open; whether they are focussed on the same point or are held parallel, or squinted, or even jammed into all sorts of relative positions by fingers inserted into their sockets, the field of each will appear to coincide with the field of the corresponding portion of the retina of the other. If an after-image be found in both together, one image only will be seen whatever their relative positions; and if the image be found on one alone, it will yet be seen in the corresponding portion of the field of the other, provided that the brilliancy of the second field be not so great as to obscure the much weaker sensation of the image. In reality, in this experiment the after-image never does appear on the left field until the last eye has so greatly darkened as to allow it to be seen; and in the periodical increases in brilliancy of the left field the image disappears. It will thus be seen that a retinal seat of the after-image explains all the facts as easily as does a central seat. Hence the assumption of the latter by M. Binet and others is entirely superfluous * * * not merely superfluous, but impossible."[1]

+ The results of five experiments tend to strengthen this position: (1) There is a difference in brightness of the image when the stimulated eye is open or shut. (2) With an image in the right eye, open it and the image is clearly seen; open the left eye with the right closed, and the image is blotted out. Such an effect is probably due to binocular mixture. (3) With both eyes open, the image being in the right, place a pencil or

[1] Delabarre, E. B., On the Seat of Optical After-Images; *Amer. Jour. Psych.*, II., 326–328. 1889.

similar object before the left; no change in the image occurs. Place an obstruction before the right, and the image disappears temporarily or permanently. (4) Obtain a strong image with the right eye; if projected on a white surface, it appears *light green*. If both eyes are covered tightly, so that no light gets in, the image is *dark green*. If the eyes are closed, but not covered, and light gets in, the image is *rose-colored*. Now "obtain an image with the right eye, then close and cover it and open the left eye. Now the left field darkens and the *dark-green* after-image appears; this gives place to the *rose-colored* image if the covering is removed from the right eye, and the eye kept closed; and this in turn to the *light green* if the right eye is opened. These three colors can be made to succeed one another indefinitely without in any way interfering with the open left eye, which, alone, according to M. Binet, is the source of all the visual impressions present." (5) In retinal rivalry, on obtaining an image with the right eye, look with both eyes through colored glasses at a background. When the color seen with the right eye is predominant the image is seen; when the color seen with the left eye is predominant no image is apparent.

Professor Titchener's experiments, like Binet's, may also be explained by considering the image a peripheral as well as a central event. The variation in brightness is explained from the peripheral point of view, to my satisfaction, by Delabarre's considerations. The apparent difference in the duration of the image is readily understood when one learns that pressure of any sort on the eye will disturb the image. The mere closing of the eyelid would suffice for this. When Titchener speaks of the occurrence of the phenomena even under 'conditions when a mixture of both fields is impossible,' he seems to forget that the two eyes always act as one, and that it is impossible to tell (by ordinary inspection) in which eye a sensation is. One of the subjects used in the present research, a man who had worked during two years upon binocular rivalry, advises me that he is now unable, even after such great practice, to tell in which eye the sensation is. It seems probable, in view of other experiments noted above, that Dr. Titchener's subjects were in-

fluenced to a great extent by *suggestion*. It has been seen what a great part this plays in the duration and in the spatial character of the after-image; and it is not unlikely that a similar influence is felt when looking for an image with an unstimulated eye.

To my mind, the only experimental results that might indicate the central seat of the after-image are the well-known experiments with suggested after-images. Binet gives the following account of the experiments:[1] "Wundt has shown that the simple image of a color, imagined for a long time, gives rise to an after-sensation of the complementary color. If one mentally looks fixedly for some time at a red image, he perceives a green tint upon opening the eyes and looking toward a white surface. This experiment is difficult to repeat, for it is necessary to have a power of visualization that not every one has. To take me as an example, I am not even able to imagine a color clearly. I am a very mediocre visualizer, so it is not surprising that I cannot obtain the colored after-image. But my friend Dr. Féré does this readily. He can represent to himself a red cross sufficiently intense to see on a piece of paper a green cross following it; moreover, he sees not only the color but the shape." A similar experiment has been made with hypnotized subjects. A red cross is suggested and then suggested away, and the green after-image noted. In the case mentioned by Binet, however, it seems not to have occurred to him that possibly the resultant after-image was suggested just as was the original red cross. The experiment has not been made in a rigidly scientific manner, and is inadequate. I have been unable to get a sufficiently good visualizer who was at the same time naïve regarding after-images, and I have not been able to repeat the experiment with due precautions.

The case with a full hypnotized subject seems not well authenticated. However if the question of its authenticity be waived for a moment, the question immediately arises, "Is the after-image the result of seeing the imaginary red cross, or is it not in this case also a new suggestion?" The precaution not to give such a suggestion seems not to have been taken, and this

[1] La Psychologie du Raisonnement, Paris, 1886, p. 41.

would vitiate the experiment. Even if this precaution were taken and the same result found, the central hypothesis would not be proven. Other experiments with hypnotized subjects would seem to indicate that from suggestion certain tissues may be modified so as to leave thereafter a noticeable effect. This is true of the experiments in which a blister is produced by suggesting the application of some known medium which ordinarily will produce such an effect. With such a case explained upon purely peripheral grounds, would it not seem probable that the eye was also so stimulated when the red cross was imagined?

Delabarre suggests the following experiment, a trial of which might aid in giving some negative testimony. Hypnotize a subject and suggest a sensation that he may get a good after-image. Then by suggestion paralyze the sight of this eye. If no after-image is seen in the other eye, it will indicate that there is no transfer; and if an image is presumably seen, "it will merely indicate that the paralysis of the right optic nerve has not been complete."[1] Delabarre's radical statement should have its *will* toned to *may*. The result in either case would not decide whether the image was central or peripherally transferred.

An experiment which may indicate a line for investigation has been tried by me. I attempted to stimulate only the optic nerve and the cerebral visual centers to discover what effect, if any, was left by such stimulation. Electrodes were placed upon the head, and when the circuit was closed and broken a vivid flash of light was produced. All the experiments gave negative results. No after-image was produced. It would be supposed that, if the image was of central origin, the stimulation of the central centers would give such an after-image. In this experiment it is not certain that the retina was not stimulated, but that the brain center was (either directly by the electricity or by the retina, which was in turn stimulated by the electric current). It would seem as if an after-image should have been produced in either case if the seat was cerebral.

Another experiment, which gives only a partial and negative answer to the question of transfer, has been made by me.

[1] Op. cit.

That portion of the right eye which corresponds to the blind spot of the left eye was stimulated to see whether there would be an apparent transfer. If a transfer (apparent) occurred, it could not be accepted as real, since with the corresponding portion of the left eye we can see nothing. If no image is apparent on opening the left eye, we learn nothing new, and neither theory is benefited. The fact is, an image appeared upon opening the left eye, and we are left to conclude that the transfer in this case *is* apparent and in other cases it is *likely to be* apparent.

Such an experiment is of value in that it is a link in the evidence tending to exclude one hypothesis. The image seems not to be transferred, but is either central or peripheral. The central situation seems to me improbable in view of the results of Delabarre's experiments and of the experiment on brain stimulation. The changes in the image under objective changes in the organ originally stimulated indicate a peripheral seat only in the stimulated eye; and the interference with the stimulated eye interfering with the progress of the image indicates that the after-image is not transferred.

PART II. HISTORICAL AND DESCRIPTIVE.

SECTION 9. RELATION OF AFTER-IMAGES TO SENSATION, TO IMAGINATION AND TO MEMORY.—The intimate relation of after-images to sensation, to memory and to imagination makes the phenomena of great psychological interest. Seeming to be the connecting link between sensation and the idea, the study of this relation is of considerable epistemological importance.

The differences between visual after-images and the images of the imagination have been thoroughly discussed by Fechner.[1] His conclusions are summarized by James as follows :[2]

"*After-images* first coercive; seem unsubstantial, vaporous; are sharp in outline; are bright; are almost colorless; are continuously enduring; cannot be voluntarily changed; are exact copies of the originals; are more easily got with shut than with open eyes; seem to move when the head or eyes move; the field within which they appear (with eyes covered) is dark, contracted, flat, close to the eyes and the images have no perspective; the attention seems directed forward toward the sense organ in observing after-images." On the other hand, "*imagination-images* feel subject to our spontaneity; have, as it were, more body; are blurred; are darker than the darkest black of the after-images; have lively coloration; incessantly disappear and have to be renewed by an effort of the will (at last even this fails to revive them); can be exchanged at will for others; cannot violate the necessary laws of appearance of their originals; *e. g.*, a man cannot be imagined from in front and behind at once; the imagination must walk around him, so to speak; are more easily had with open than with shut eyes; need not follow the movements of head or eyes; the field is extensive in three dimensions, and objects can be imagined in it above or behind almost as easily as in front; in imagining, the attention feels as if drawn backwards towards the brain. Finally Fechner speaks of the impossibility of attending to both after-images and imagination-images at once, even when they are of the same object and might be expected to combine."

The above account is true only of Fechner himself; he remarks that results from other individuals show certain characteristic differences. Dr. Lay finds that he agrees with Fechner only in the following particulars: the after-images are coercive, cannot be voluntarily changed, seem to move with the eyes, and the attention is directed forward toward the sense organ, while the images of the imagination are directly opposite

[1] Elemente der Psychophysik, II., 468 ff.

[2] Principles of Psychology, Vol. II., 50.

in these particulars.[1] Regarding the other differences, it is not clear whether Dr. Lay disagrees with Fechner regarding the characterization of the after-image or of the images of imagination.

From the numerous observations of my subjects and myself any one of these qualifications of the after-image may be contradicted. The fact that we do not see an after-image after every visual sensation, the fact that it requires an amount of attention to perceive it, would indicate that the phenomenon is not so coercive as Fechner believed. The after-images are not colorless; sometimes they are colored more lively than ordinary sensations, and often their color is more intense than that of the imagination-images. The images are not continuously enduring, but have many fluctuations. We have already seen (Part 1, Sec. 7) that the after-image often has the appearance of solidity. The probable reason for the usual two-dimensional character lies in the fact that nearly all objects bright enough to produce after-images are of two dimensions only. The colored paper, the window panes, the gas flame, etc., are plane surfaces and in the sensation the effect of solidity is not gotten directly from these, but rather from their surroundings, which usually have not the requisite intensity for the production of after-images. To Fechner's differences it may be added that the after-image is sharp and clear only if very near the point of fixation, while the imagination-image may be a clear representation of a scene all of which could not be noted by the eye at one time. James adds as a universal proposition that the after-images seem larger if we project them on a distant screen, and smaller if we project them on a near one, while no such change takes place in mental pictures.[2]

The name of memory-after-image is given by Fechner to the instantaneous positive effects of sensation.[3] These images are distinguished from ordinary after-images by the following characteristics: (1) Their originals must have been attended to

[1] W. Lay, Mental Imagery, p. 2. Monograph Supplement No. 7 to *The Psychological Review*, 1898.

[2] Principles of Psychology, p. 51, note.

[3] Elemente der Psychophysik, II, p. 491 ff.

only such parts of the compared originals as have been attended to appearing: this is not the case in common visual after-images. (2) The strain of attention toward them is inward, as in ordinary remembering; not outward, as in observing an ordinary after-image. (3) A short fixation of the original is better for the memory-after-image; a long one for the ordinary after-image. (4) The colors of the memory-after-image are never complementary of those of the original. It is difficult to state the relation between the memory-after-image and the memory-image, but the two seem almost equally different from the true after-image. Many memory-after-images have an overpoweringly coercive quality. Examples of this are numerous. A revolting scene will often leave a lasting memory-image. The sight of some one drowning or a railway accident will remain in the mind for weeks; the details will appear in consciousness unexpectedly, and will overpower us as did the originals. But the effect is not produced so often with the visual as with the auditory memory-after-images. The snatches of melody that one hears continually in the mind's ear after a concert, or the popular tunes that often rise in consciousness and compel us to hum them over and over again, have a coercive quality unparalleled in the phenomena of after-images.

In many ways the after-images can be considered a true sensation. One of the chief sensational conditions is present, viz., a change in the sense organ; and many of the more mental conditions of the sensation are equalled. At times it is impossible to say whether it is an after-image or a sensation that is in consciousness. A friend relates that his child, who had looked at the sun and then turned around, tried to point out to a sister the second sun (*i. e.*, the after-image, which was *real* to him). Older people sometimes make the same mistake, and correct the error only from later observations. Such an uncertainty is due primarily to a wonderful clearness of outline, brightness of color and great intensity of the after-image. To these *differences* Sully[1] adds "definiteness of localization (either in the field of objects if the eyes are open, or in the dark field if they are shut)." Such conditions are not often produced in one's daily

[1] The Human Mind, I., p. 178.

life, but may be obtained by suitable experiment. On the other hand, the moving of the after-image with the eye, its fluctuations, its negative quality, its (usually) plane character, and the fact that it is not doubled by lateral pressure upon the eyeball, differentiate the after-image from a sensation.

SECTION 10. HISTORY.[1]—The phenomena variously known as after-images, recurrent-images and ocular spectra (Germ. *nachbilder;* Fr. *couleurs accidentelles, persistence des impressions*) seem to have been noted first by Aristotle. He compared the images of the dream state to them, and speaks of them as if they were familar to his audience. The account is as follows:

"It is evident that when we look at anything for a long time, and then turn away our eyes, the sensation continues; just, for example, as when we look at something dark after having looked at the sun, it happens that on account of the force from the light still remaining in our eyes we see nothing (*i. e.*, of the shaded object). And if, after having looked at a color for a long time we turn away our eyes, this same thing happens; and if we should turn away our eyes after having looked at the sun or some other bright object, it happens that the eye sees first the same color, this color then changes to red, then to purple, and after becoming black disappears."[2]

Later the after-image is mentioned by St. Augustine, and by the Arab Alhazin, who was probably attracted to their study from reading Aristotle's works.

In the seventeenth century (according to Helmholtz, in 1634) Peiresc "observed 1000 times that when he had looked upon the window distinguished with wooden bars and squares of paper, he carried the form thereof some time after in his eyes; but with this difference, that if he kept his eyes shut, he seemed to behold the bars dark, and the paper squares white, as he had at first seen them; but if he looked with his eyes upon a dark wall, then the paper squares seemed dark, and the bars of the same whiteness with the wall."[3]

Kircher, Mariotte, Boyle, Fabri, in the succeeding century

[1] A short historical résumé will be found in Helmholtz, Physiol. Optik, 2 Aufl., pp. 836-837.

[2] De Somniis.

[3] Life of Peiresc, London, 1657, Book IV., p. 101.

made slight additions to our knowledge regarding the appearances. Newton's account of his memorable after-image (see Part I., Sec. 4, p. 37) was sent to Locke about this time. In it he seems to be the first after Aristotle to call attention to their intimate relation to the more (so-called) mental images.

Buffon[1] in 1743 related his experience with after-images projected on differently colored backgrounds. He found that the image fused with the background, and formed a color which was a combination of the true color of the after-image and that of the background. On account of the variety of the phenomena and because he was unable to account for all the appearances, Buffon called the after-images '*couleurs accidentelles*.' These experiences of Buffon were later confirmed by Gergonne, who made a number of new experiments similar in character.

The first theory after Aristotle's (=continuation of the stimulus) was that of Jurin (1758?). Apparently considering only the negative phases, he regarded the after-image as due to a process in the retina the reverse of what went on in normal sensation. In expression this view is strikingly like some most recent ones, although Jurin had not the same ideas as the more modern writers.

Scherffer[3] (1761), noting the negative images on a light background, supposed the phenomena to be caused by a temporary loss of sensibility of the retina for one color. He thought that the eye, having undergone a prolonged action from rays of a certain color, lost momentarily its sensibility for a weaker stimulus of rays of that color. Thus, on looking at white the eye is stimulated by rays of light of different color—red, green, blue, etc., and the retina recombines these into white. Now, after having looked for a time at red, the retina becomes fatigued for rays of that color, and when a white object is then fixated the various rays composing white are seen with the exception of the red, thus producing a bluish-green image.

[1] Mémoires de l'Acad. des Sciences de Paris, 1743, p. 213.

[2] Essay on Distinct and Indistinct Vision, p. 170 ff, of Smith's Optics, Cambridge, 1738.

[3] Dissertation sur les couleurs accidentelles; *Jour. de Physique*, XXVI., 1785.

Plateau[1] conclusively shows that this theory is inadequate in that it does not account for the negative after-images which are seen perfectly in most complete darkness. A later theory proposed by Scherffer was that the after-image is due to a prolongation of a feebler stimulation produced by rays different from the dominant color. For example, in looking at a red square we see not only red light, but also some blue and green light, and when the red is taken away the blue and green, which have not been too intense to overpower the eye, continue to be seen, thus producing the after-image. Were this true, it would be an example of a lesser light having a greater effect than one of great intensity.

De Godart[2] is responsible for two (so-called) theories. The first of these is a very fanciful one. Arranging the colors like the tones in a musical scale (black, blue, green, red, yellow, white), he believed that the direct continuation of a sensation was as much lower than white as the sensation was higher than black. A sympathetic action was set up in the retina just as sympathetic tones are noted on a musical instrument. "Such a theory," Plateau remarks, "scarcely needs refutation." The other theory of De Godart is as follows:

> Voici une autre théorie de ces phénomènes: c'est de dire tout uniment qu'une fibre ébranlée par un objet reste incapable de donner la sensation d'un autre, aussi longtemps qu'elle conserver l'impression du premier, et que les différentes couleurs étant experimées par des portion d'une même fibre d'autant plus, courtes que le ton de la couleur est plus vif, c'est la partie qui n, a pas joué qui excitée par le blanc a le faire, donne la couleur accidentelle.[3]

This seems to be only a badly conceived, a poorly expressed theory of insensibility like that proposed by Schaeffer; and coming, as it does, without elaboration toward the close of his paper, it seems to indicate that the hypothesis is not well considered by the author.

Darwin[4] (R. W.), having considered all the known facts,

[1] Essai d'une Théorie générale comprenant l'ensemble des apparences visuelles qui succèdent à la contemplation des objets colerés. * * * la persistance des impressions de la Rétine, les couleurs accidentelles, etc.; *Ann. de Chimie et de Physique*, LVIII., 337–406, 1835.

[2] *Jour. de Physique*, VIII., 1776.

[3] *Ibid.*

[4] R. W. Darwin, New Experiments on Ocular Spectra of Light and Colours; *Philos. Trans.*, LXXVI., 313–348, 1786. Also found in E. Darwin's Zoonomia, 4 Am. Edit., 1818, Vol. I., p. 443–466. See also Vol. I., p. 10 ff.

attempted to group them into four classes: (1) Images owing to a less sensibility of a defined part of the retina. (2) Images owing to a greater sensibility of a defined part of the retina. (3) Images that resemble their object in color as well as form. (4) Images that are of a color contrary to that of their object. From the consideration of these different facts, he was led to believe that a part of the retina became fatigued by a color and became insensible to rays of that color, and that this part of the retina then took up a mode of action opposite to that which produced the sensation. The details of this theory are interesting in view of what is at present known of the retina's action. He says "the effect of the activity of the retina may be to alter its thickness or thinness, so as better to reflect or transmit the colours which stimulate it into action."[1] Possibly "the muscular actions of the retina constitute the sensation of lights and colours; and the voluntary repetitions of them, when the object is withdrawn, constitute our memory of them."[2]

Contrast was used as an explanation by C. A. Prieur (or Prieur de la Côte d'Or. [Fechner]). Numerous observations were made in the succeeding years, but they were only slight variations from the previous work. They are unimportant.

In 1835, Brewster[3] discussed the various color-changes, and concluded that the primary color and the color of the after-image existed in the retina simultaneously, in the same manner as a fundamental tone and its harmonic. After the primary light has ceased the color of the after-image continues. This is almost identical with the first theory of de Godard. In constructing his theory Brewster seems to rely greatly upon the various phenomena of simultaneous contrasts, considering these as representatives of the after-image process.

Having considered the inadequacy of each of the foregoing theories from Jurin to Brewster, Plateau[4] made a careful ex-

[1] *Philos. Trans.*, LXXVI., p. 348.

[2] *Ibid.*

[3] In Edinburgh Encyclopedia, Vol. I., article *Accidental Colours.* Also *Philos. Mag.*, IV., 354, 1834.

[4] *Ann. de Chimie et de Physique*, LVIII., 337–406.

amination of all the known facts preparatory to constructing a new theory. His theory, which follows, is partly a combination of the ideas of his predecessors, particularly those of Jurin and Darwin. He says, "we must conclude that the accidental image results from a particular modification of the organ, which spontaneously gives us a new sensation." "When the retina has undergone the action of rays of a certain color, it resists the action of that color and tends to regain its normal state with a force more and more intense. Then if the excitation is suddenly removed, it returns to its normal state by an oscillatory movement as much more intense as the action has been prolonged." The first primary image, which he considered a prolongation of the stimulus, was noted by him, and he concludes "that when the retina, after having been excited for some time by the presence of a colored object, is suddenly removed from this excitation, the sensation produced by the object continues to exist for a very short time, after which the retina spontaneously takes on a state opposite to the first, whence there results the sensation of the accidental color.

Dove, Scoresby, Grove, Seguin, Brücke and Aubert noted the after-images of moving objects, and the appearance and reappearance of the images under increased and decreased eye illumination. Brücke and Aubert noticed the after-images resultant from instantaneous illumination by the electric spark.

Fechner, who lost his eyesight mainly because of his long-continued study of after-images from very bright lights, proposed the theory which has usually been associated with the name of Helmholtz, viz., that the positive phase of the image is a continuation of the stimulus, and the negative and complementary phases are due to retinal exhaustion. This hypothesis is the one accepted by Wundt. The theory is inadequate because it does not account for an after-image whose course (fluctuation) is as follows: Pos., neg., neg., pos., pos., neg., neg., neg., etc.

Hering regards the positive after-image as a continuation of the stimulus, and the negative phases as reactions of the visual elements to a state of equilibrium, the 'assimilation or dissimilation in some of the visual substances.' The theory of light

sensation proposed by Mrs. Franklin would account for the phenomena in approximately the same manner. It will be noticed that both these theories are in terms, though not wholly in sense, the same as Darwin's.

Accepting the general theoretical position of the Young-Helmholtz hypothesis of color vision, Bidwell would account for the phenomena as due to a 'reaction of the violet nerve fibers only.'[1] Four reasons are given for this view: "(1) With white light the recurrent colour is violet. (2) In the recurrent spectrum of the complete spectrum no colour but violet can be detected. (3) A pure red light, however intense, gives no recurrent image. * * * (4) The apparently blue colour of the ghost of simple spectrum yellow is just as well produced by a compound yellow consisting of green and red, the latter of which is inert when tested separately." It should be remarked, however, that some of these observations have been disputed, and there is always danger of accepting a theory which is proved by experiments devised after the acceptance of the theory.

It is to be regretted that all these theories have made little addition to our knowledge regarding the phenomena. Except the work mentioned in Part I., not very much has been learned regarding the conscious after-images since Fechner's time. The mixing of colors by means of discs and the summation effects of intermittent retinal excitation, have largely been considered during this time, but in a historical account of the appearances, these investigations have little place.

[1] On the Recurrent Image following Visual Impressions; *Proc. Roy. Soc.*, LVI., 140, 1894.

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